Volume 13 NOVEMBER 1929 Number 11

BULLETIN

of the

American Association *of* Petroleum Geologists

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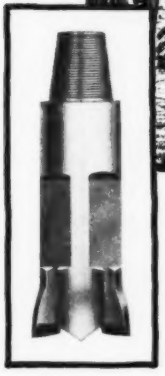

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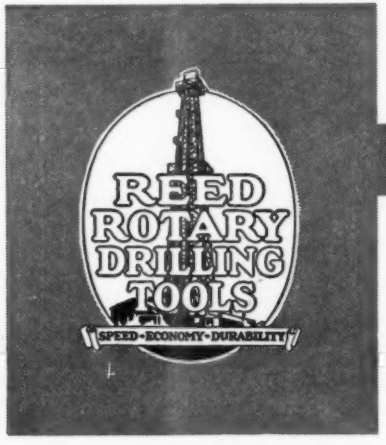

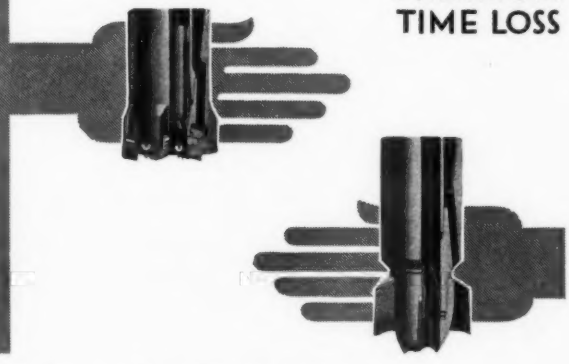

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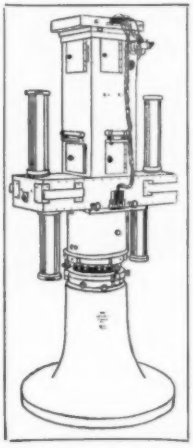

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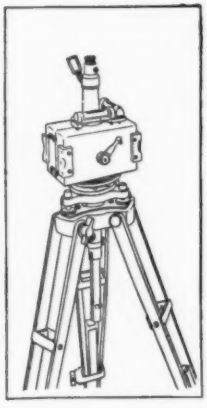

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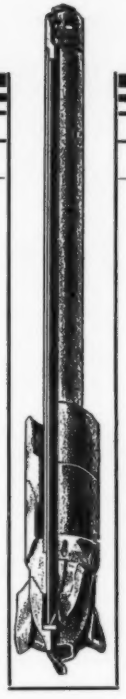

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Yates Oil Pool, Pecos County, Texas

By RAY V. HENNEN and R. J. METCALF

(Illustrated by 3 photographs, 5 maps, 2 geologic sections, and many tables)

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Volume 13 Number 11

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NOVEMBER 1929

CORRELATION OF THE PERMIAN OF SOUTHERN UTAH, NORTHERN ARIZONA, NORTHWESTERN NEW MEXICO, AND SOUTHWESTERN COLORADO[1]

A. A. BAKER and JOHN B. REESIDE, Jr.[2]
Washington, D. C.

ABSTRACT

The Permian of southern Utah, northern Arizona, northwestern New Mexico, and southwestern Colorado is conceived as bounded below, except in the Grand Canyon, by conformable Pennsylvanian limestone (Callville limestone in the extreme west, an unnamed unit in north-central Arizona, Hermosa formation in San Juan Valley and southwestern Colorado, Magdalena limestone in northwestern New Mexico), and above by unconformable Triassic deposits (Moenkopi formation, Shinarump conglomerate, and Dolores formation, in order from west to east). In the Grand Canyon the underlying beds are Mississippian (Redwall) limestone. Three main types of Permian sequence occur: that of the Grand Canyon, with the Supai formation and Hermit shale (red beds), Coconino sandstone (light-colored, cross-bedded), and Kaibab limestone, named in ascending order; that of Monument Valley and adjacent country north and south, with the Rico formation (red beds and limestone) below and five units above, here treated as parts of the Cutler formation and named in ascending order the Halgaito tongue (red beds), Cedar Mesa sandstone member (light-colored, cross-bedded), Organ Rock tongue (red beds), De Chelly sandstone member (light-colored, cross-bedded), and Hoskinini tongue (red beds); that of southwestern Colorado, with the Rico formation (red beds and limestone) below and the undivided Cutler formation (red beds) above. The relations of these units to one another are shown in a number of cross sections and the earlier nomenclatures are correlated with that used here. Apparently the Permian began with the widespread deposition of red beds derived from the east, except in the extreme west part of the area where light-colored sands were laid down. In the east a few marine limestones (Rico) interrupted the sequence of red materials, representing incursions of a sea from the east. These first red deposits were followed by light-colored sands coming from the northwest (Cononino, et cetera), which inter-

[1]Read before the Association at the Fort Worth meeting, March 22, 1929. Manuscript received by the editor, July 29, 1929. Published by permission of the director of the U. S. Geological Survey.

[2]Geologists, U. S. Geological Survey.

fingered with the red materials that still continued to come in from the east. Then marine waters gradually advanced from the west across the western half of the area, depositing chiefly limestone (Kaibab). East of the sea the light-colored sandstones were the chief deposits in a wide zone, and still farther east the red materials prevailed. Finally, the sea withdrew with seeming abruptness and the whole area was exposed to the period of erosion represented by the unconformity at the base of the Triassic.

SCOPE OF PAPER AND SOURCE OF DATA

In this paper the writers offer a correlation of the Permian deposits of a large area in Utah, Arizona, Colorado, and New Mexico, mostly in the Plateau province, but on the east extending into the Rocky Mountain province. In this area, shown in Figure 1, conditions of sedimentation differed much between local regions at a given time and changed often with time, the net effect being to produce materially unlike sequences of deposits at not widely separated places. Considerable difference of opinion about relationships and appropriate nomenclature has naturally existed, and the present contribution, by reinterpreting previously published information and recording many new data, is designed to aid in clearing up at least some of the disputed matters.

The data given here are in part taken from the literature, and checked, for many localities cited, by visits by one or both of the writers. In larger part, however, the data are derived from detailed mapping in 1926, 1927, and 1928 by U. S. Geological Survey field parties and from reconnaissances made in connection with this work. The parties in 1926 and 1927 were in charge of E. T. McKnight, C. H. Dane, and A. A. Baker. C. E. Dobbin and J. B. Reeside, Jr., were associated with them for various periods. In 1928 a party under Mr. Baker mapped in detail an area in southern Utah south of San Juan River, and in extension of the stratigraphic part of this project the writers made several reconnaissance trips in southeastern Utah and adjacent parts of the three adjoining states. H. E. Gregory joined them for ten days at the beginning of the season. In this reconnaissance work practically all of the important localities were visited, including some new to the writers and others previously examined but reviewed in the light of accumulated later information.

CHARACTER OF THE REGION

Almost all the area under discussion is part of the Colorado Plateau. The rocks in general are flat-lying or but slightly inclined. Toward the west a few large faults disturb the strata, and toward the east several anticlines, in part faulted, and several laccolithic mountain masses break the regularity of the beds. The region is deeply dissected, vegeta-

tion is generally scant, and exposures continuous for many miles. On the whole it is ideal country for determining lateral relations of the stratigraphic units.

UPPER AND LOWER LIMITS OF THE PERMIAN

In the region under discussion the two planes which may be taken as convenient lower and upper limits of the Permian have been in recent years the subject of fairly general though not unanimous agreement.

The lower limit is the top of a zone of Pennsylvanian limestones represented in the extreme west by such units as the Callville limestone of the Muddy Mountains of Nevada; farther east by limestones originally placed at the top of the Redwall limestone by various authors, and more recently considered by Darton[1] to deserve separation as an independent unit between Redwall and Supai, wherever the units can be distinguished; still farther east by the Hermosa formation, extended in this paper to apply to the Pennsylvanian part of the "Goodridge formation" of the San Juan valley of Utah; and by the Magdalena limestone of northwestern New Mexico. In the Grand Canyon, White reports[2] Permian plants from beds resting unconformably on Mississippian (Redwall) limestone, a part of the section originally considered of Pennsylvanian age and assigned to the Redwall, later placed in the Supai but still considered Pennsylvanian. At several places pre-Cambrian crystallines rise high enough into the section to form the basement beneath the Permian. In general, however, Pennsylvanian limestones are the underlying rocks.

The upper limit is afforded by the unconformable base of the Triassic. Over much of the region the lowest Triassic is the Moenkopi formation, containing in the west fossiliferous marine deposits in the lower part, but in the east non-fossiliferous red beds of very characteristic lithology. Still farther east the Moenkopi formation is absent. At places the Shinarump conglomerate rests on the Permian beds; at other places the Shinarump is not recognized, but the Upper Triassic Chinle formation or the Dolores formation rests on them.

MAIN TYPES OF LITHOLOGIC SEQUENCE

Three main types of lithologic sequence are present in the area covered by this paper—one shown by the Grand Canyon section in

[1] N. H. Darton, "A Résumé of Arizona Geology," *Univ. of Arizona Bull. 119* (1925), p. 72.

[2] David White, personal communication.

central Arizona, a second by the section in Monument Valley in southwestern Utah, and the third by the section in the Rico Mountains in southwestern Colorado. A fourth, of much less importance here, is shown in the Zuni Mountains of northwestern New Mexico.

In the Grand Canyon section the Permian begins with the Supai formation, of red sandstone and shale with some limestone in the basal part, resting unconformably on the Mississippian Redwall limestone. Upon the Supai lies the unconformable red Hermit shale and then buff to gray-white, cross-bedded Coconino sandstone, and upon it in turn the marine Kaibab limestone, a unit of several massive limestone members separated by softer members of sandstone, shale, and gypsum. Above the Kaibab lies the unconformable Lower Triassic Moenkopi formation. This general sequence is found in the region west of a curved line extending from Holbrook, Arizona, on the south, to the junction of San Juan and Colorado rivers and thence northward in Utah to the San Rafael Swell. Some departures from regularity are: the Hermit shale has not been generally identified outside of the Grand Canyon and has not usually been separated from the Supai formation; eastward the Kaibab limestone thins as a distinct unit until it disappears; westward the Supai formation loses much of its red coloring, and the Coconino sandstone thins until it is unrecognizable; westward also Pennsylvanian beds appear in the section and become thick and important.

In the Monument Valley section the Permian begins with a unit of interbedded marine limestones and red beds constituting the uppermost part of the "Goodridge formation," to which in this paper the name Rico formation is extended. Beneath the Rico formation lies the remainder of the "Goodridge," to which the name Hermosa formation is extended. Upon the Rico formation lies a conformable series of five lithologic units—red beds much like the Supai formation alternating with light-colored cross-bedded sandstone much like the Coconino sandstone of the Grand Canyon region. Above this series lies at most places the Moenkopi formation, but towards the east it is absent and the Shinarump conglomerate rests directly on the Permian. This sequence occurs throughout the area from the edge of the Kaibab limestone eastward to a line not accurately known but extending approximately southeast from the junction of the Green and Colorado rivers. The details vary much from place to place, not all the members being present everywhere, and the nomenclature which has been applied in the area has been much confused. In general an effort has been made to use the Grand Canyon terminology, but the results have not been satisfactory. In later pages

a nomenclature is offered in which the name Cutler formation is extended to the series of beds above the Rico formation and local member names are used for the variable parts of it.

In the Rico Mountains the Permian begins with the Rico formation, which rests conformably on the Hermosa formation. Conformably above the Rico formation lies the Cutler formation. Both Rico and Cutler are dominantly red arkosic shales, sandstones, and conglomerates, the Rico, however, containing some marine fossiliferous limestones. Nothing comparable with the Kaibab limestone or with the light-colored cross-bedded sandstones is present. Next above the Cutler in Colorado lies the Triassic Dolores formation, though in Utah in the Moab region the Lower Triassic Moenkopi formation is present and at other places the Shinarump conglomerate or Chinle formation rests on the Cutler formation.

In the Zuni Mountain region a sequence of beds somewhat different from those enumerated in the preceding paragraphs appears above the Pennsylvanian Magdalena limestone. It has been divided into the Abo sandstone below, a brownish-red slabby sandstone yielding marine fossils in the lower part, and the Chupadera formation above, an alternation of limestone, sandstone, and gypsum which yields fossils in part identical with those of the Kaibab limestone. Red beds above the Chupadera have been assigned in the literature to the Moenkopi formation, but the writers believe them to be chiefly, if not all, Permian. The next overlying beds are the Shinarump conglomerate and then the Chinle formation.

Figures 2 and 3 show sections typical of the first three regions, and Figures 5 and 6 show the section in the fourth.

RELATIVE VALUE OF DATA

The quality of the data used in this paper varies somewhat because of the large size of the area covered. Within the areas adjacent to the Colorado and Green rivers and the area south of San Juan River in Monument Valley, where detailed mapping was carried out, the degree of certainty is high, especially as in these areas the exposures are continuous throughout long distances. In the intervening areas and southward in Arizona enough work has been done to assure a reasonable degree of certainty. A relatively small gap between the Defiance uplift and Monument Valley is practically eliminated by the presence of an identical section on both sides. Enough work in detail and reconnaissance has been done by various persons in the Grand Canyon region also and westward from it to establish a reasonable degree of certainty. It is not pos-

sible, however, to make direct connections between the region where Kaibab limestone is present and the region on the east because of the presence of a belt of post-Permian rocks of varying width—35 to 40 miles in the north between San Rafael Swell and the canyon of Green River near its mouth, and perhaps 70 miles in the south between Lees Ferry and the mouth of Nokai Creek or between Holbrook and Fort Defiance. Correlations across this belt are all inferred on the basis of similar sequence, lithology, and a few fossils. Between the San Juan Mountain region and the exposures of Permian rocks on the west a direct connection is not possible because of a belt of post-Permian rocks. Here, however, the identity in sequence and lithology, and the presence of the Rico fauna in the lower part serve to establish a satisfactory correlation across the concealed belt.

REGIONAL CORRELATIONS

The correlations offered here will be shown by a series of seven straight-line cross sections in various directions across the regions concerned, all based on local measured sections, and finally by a composite of these in a perspective diagram. The location of these cross sections is shown in Figure 1.

Muddy Mountains, Nevada, through Monument Valley, Utah, to the Rico Mountains, Colorado (Fig. 2).—This diagram shows a complete sequence of change from the section of Grand Canyon type through that of Monument Valley type to that of the San Juan Mountain type. In the Muddy Mountains,[1] Nevada, and at Hacks Canyon[2] and Lees Ferry,[3] Arizona, gross units similar to those differentiated in the Grand Canyon are present. In the Muddy Mountains the Supai formation is composed of pink sandstone, some red shale, gypsum, and minor limestone 1,485 feet thick. Hermit shale is not recognized, and Coconino sandstone is absent. At Hacks Canyon Reeside and Bassler assigned to the Supai the 1,075 feet of beds exposed beneath the 90 feet of Coconino sandstone, but Gregory and Noble[4] later assigned the upper 550 feet of this to the

[1]C. R. Longwell, "Geology of the Muddy Mountains, Nevada," *U. S. Geol. Survey Bull. 798* (1928), pp. 31-43.

[2]J. B. Reeside, Jr., and Harvey Bassler, "Stratigraphic Sections in Southwestern Utah and Northwestern Arizona," *U. S. Geol. Survey Prof. Paper 129* (1922), p. 69.

[3]Kirk Bryan, cited by C. R. Longwell, H. D. Miser, R. C. Moore, Kirk Bryan, and Sidney Paige in "Rock Formations in the Colorado Plateau of Southeastern Utah and Northern Arizona," *U. S. Geol. Survey Prof. Paper 132* (1923), p. 16.

[4]H. E. Gregory and L. F. Noble, "Notes on a Geological Traverse from Mohave, California, to the Mouth of the San Juan River, Utah," *Amer. Jour. Sci.*, Ser. 5, Vol. 5 (1923), p. 235.

FIG. 1.—Sketch map showing location of sections presented in Figures 2-8, and of the region included in Figure 9.

Hermit shale. At Lees Ferry only a small thickness of beds is exposed beneath the Coconino sandstone and in this Bryan noted the Hermit shale with doubt. The Conconino sandstone at Lees Ferry is 300 feet thick and its westward thinning to 90 feet at Hacks Canyon and to entire absence in the Muddy Mountains is a striking feature.

Southwest of the Muddy Mountains in the Goodsprings Mountains, Nevada, Hewett[1] found a massive buff sandstone more than 400 feet thick in the midst of the 1,080 feet of Supai, though neither Coconino nor Hermit is recognizable, and all strata between the Pennsylvanian and the Kaibab limestone are placed in the Supai. Northeast of the Muddy Mountains, in southwestern Utah,[2] the Supai loses its red coloring and neither Hermit nor Coconino is recognizable, but the Supai, the Hermit, and possibly part of the Coconino seem to be represented by an

[1]D. F. Hewett, "Geology and Ore-Deposits of the Goodsprings Quadrangle, Nevada," *U. S. Geol. Survey Prof. Paper* (in press).

[2]J. B. Reeside, Jr., and Harvey Bassler, "Stratigraphic Sections in Southwestern Utah and Northwestern Arizona," *U. S. Geol. Survey Prof. Paper 129* (1922), pp. 57, 77.

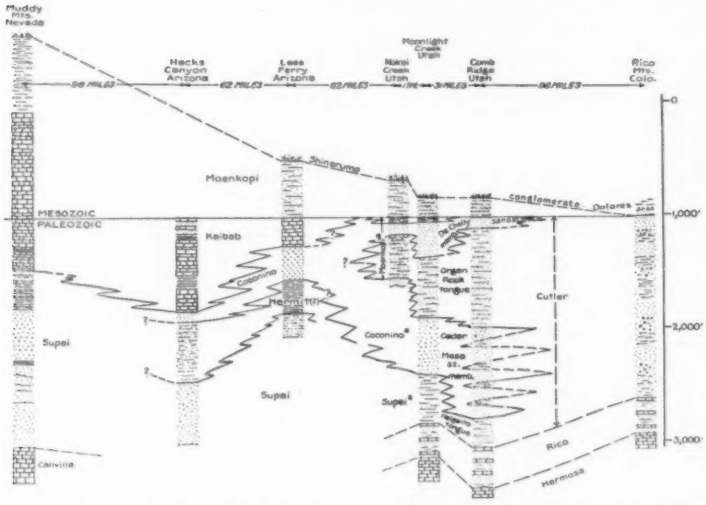

FIG. 2.—Sections from Muddy Mountains, Nevada, through Monument Valley to the Rico Mountains, Colorado. Names marked with asterisk (*) are as used in previous reports and are not accepted in this paper.

indivisible yellow sandstone unit nearly 1,500 feet thick. It seems to the present writers that the northwestward thinning of the Coconino is probably due in large part to a lateral change into Kaibab limestone at the top. The Kaibab limestone, with some gypsiferous and sandy beds, attains a maximum thickness on the line of the section of 830 feet at Hacks Canyon, Arizona. It is thicker toward the northwest away from the line of the section but somewhat thinner as differentiated in the Muddy Mountains. It thins eastward, and fades out under cover on the line of the section at some point between Lees Ferry, Arizona, and Nokai Creek, Utah. The Permian strata are concealed beneath younger sediments between these two points, and the change in stratigraphy can not be observed. The Lower Triassic Moenkopi formation overlying the Kaibab is readily recognized from Muddy Mountains to Lees Ferry, although it thins much eastward and loses the marine beds in the lower part. Its base is everywhere an erosional unconformity.

East of Lees Ferry the Permian strata reappear from beneath their cover of younger sediments at Nokai Creek in Utah, where an incomplete section is exposed. East of Nokai Creek excellent exposures for many miles in Monument Valley permit detailed study of the stratigraphy. The sequence of strata bears little resemblance to that at Grand Canyon.

The Kaibab limestone is absent and the major part of the Permian consists of two dark buff to white sandstones, each much like the Coconino, separating three red-bed units. To this group of units in this paper the name Cutler formation is extended (see page 1443). Beneath it lies what has been called by previous writers the "Goodridge formation." The upper 300 to 400 feet of the "Goodridge formation," as long ago recorded by Woodruff,[1] consists of red sandstones and shales with interbedded limestones which contain marine invertebrates identical with those of the Rico formation. In consideration of the lithology and fauna this portion of the "Goodridge formation" is in this paper designated the Rico formation.[2] The lowest of the three units of red sandy shale and sandstone resting conformably on the Rico is 250 to 430 feet thick. It has been called part of the Moenkopi formation,[3] Supai(?),[4] part of the "Monument Valley shale," of Hager,[5] and part of the "Goodridge,"[6] but is here designated the Halgaito tongue of the Cutler formation (see page 1443). In these red beds the writers found fragmentary bones that E. C. Case determined to be of Permian types. Above the lowest unit of red beds lies the lower light-colored sandstone, conspicuous in Cedar Mesa, previously called Coconino sandstone and here designated the Cedar Mesa sandstone member of the Cutler formation (see page 1443). It is a massive white sandstone 500 feet thick in Moonlight Creek. Eastward near Comb Ridge it breaks up into several massive yellowish-brown ledges separated by gypsum and red sandy shales. A short distance south of the line of the section shown in Figure 2 the massive sandstones disappear entirely and the interval of the light-colored sandstone is represented by an unbroken sequence of red sandstones and sandy shales extending from the Halgaito tongue up into the next overlying unit. The exposures are continuous, and the change may be followed throughout. Above the Cedar Mesa sandstone is the second set of red beds, those that form the picturesque landmark known as Organ Rock. This red-bed unit is thin, regularly bedded sandy shale

[1]E. G. Woodruff, "Geology of the San Juan Oil Field, Utah," *U. S. Geol. Survey Bull. 471* (1912), pp. 81-85.

[2]See also A. A. Baker and others, "Notes on the Stratigraphy of the Moab Region, Utah," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), pp. 794, 799, 805.

[3]E. G. Woodruff, *op. cit.*, pp. 86-88. H. E. Gregory, "The Navajo Country," *U. S. Geol. Survey Prof. Paper 93* (1917), p. 29.

[4]H. D. Miser, cited by C. R. Longwell and others, *op. cit.*, p. 7.

[5]Dorsey Hager, "Stratigraphy—Northeast Arizona-Southeast Utah," *Mining and Oil Bull.*, Vol. 10 (1924), p. 137.

[6]H. E. Gregory, *op. cit.*, map, Pl. 2.

and sandstone weathering into fluted, vertical faces. They have been previously referred to the Moenkopi formation by practically all writers on the region but are here designated the Organ Rock tongue of the Cutler formation. These middle red beds are 380 feet thick at the mouth of Nokai Creek and thicken eastward to 550 feet. Fossil plants determined by David White to be *Walchia piniformis* and *Yakia heterophylla* White Ms. of Permian age were found at the top of these middle beds in Copper Canyon at the Arizona-Utah state line, and bones determined by E. C. Case to be of Permian age were found near the base. At the very base of the Organ Rock tongue occur at several places thin discontinuous beds of very sandy limestone. Darton[1] reported invertebrates of Kaibab age from one of these on Moonlight Creek. The writers examined several of these lenses but found no fossils of any sort. The units are so indefinite that it seems hardly worth while to call them Kaibab limestone, though any marine invertebrates at the horizon might well be Kaibab species.

The buff sandstone which lies above the Organ Rock tongue, has been called the De Chelly sandstone by most investigators, though Woodruff[2] included it in his "Oljato sandstone." It is but 100 feet thick near the mouth of Nokai Creek, thins northeastward and is absent at Clay Hill Crossing, but a few miles away. Southeastward it thickens until at 10 miles above the mouth of Moonlight Creek it is 300 feet thick. It thins again northeastward from that point to a thickness of 100 feet at Comb Ridge, where it dips below younger sediments, and it disappears northward along Comb Ridge. Probably if it were not eroded off along San Juan River from Nokai Creek eastward to Comb Ridge its thickness would stand in this direction at about 100 feet, and it would fade out northward from the line of section. The uppermost series of red beds is 60 feet thick at Nokai Creek and is separated from the overlying red beds of the Moenkopi formation by an erosional unconformity. This series of red beds, consisting of sandy shales and sandstones which stand in a vertical fluted face, thins eastward and is absent at Comb Ridge. The name Hoskinini tongue of the Cutler formation is here applied to it (see page 1443). Where the De Chelly sandstone disappears at Clay Hill Crossing the Organ Rock and Hoskinini tongues unite to form one red-bed unit.

At Comb Ridge the Permian sediments dip eastward below younger sediments. In the Rico Mountains, Colorado, they are again exposed as

[1]N. H. Darton, "A Résumé of Arizona Geology," *Univ. of Arizona Bull. 119* (1925), p. 207.

[2]E. G. Woodruff, *op. cit.*, p. 87.

the Cutler and Rico formations, the former consisting entirely of coarse, arkosic red beds and the latter of red beds containing marine limestones. The stratigraphic relations disclosed in Arizona and Utah, as will be brought out in subsequent description, indicate that the red beds in the Cutler formation are essentially equivalent to the five lithologic units between the Rico and Moenkopi formations in Monument Valley.

Sycamore Canyon, Arizona, through Monument Valley, Utah, to Fisher Valley, Utah (Fig. 3).—This cross section also shows a complete change in lithology of Permian sediments from the type found at the Grand Canyon to that of the red beds of western Colorado. At Sycamore Canyon, Arizona,[1] and Little Colorado River near Moenkopi Wash,[2] in Arizona, the sections closely resemble that at the Grand Canyon with red sandy shales and sandstones of the Supai formation, light-colored Coconino sandstone about 600 feet thick, and Kaibab limestone about 325 feet thick. Hermit shale has not been identified at these localities. The Supai formation rests on Redwall limestone, which, as identified by Robinson at Sycamore Canyon, was reported to contain Pennsylvanian fossils in the upper part but at Little Colorado River is Mississippian only.

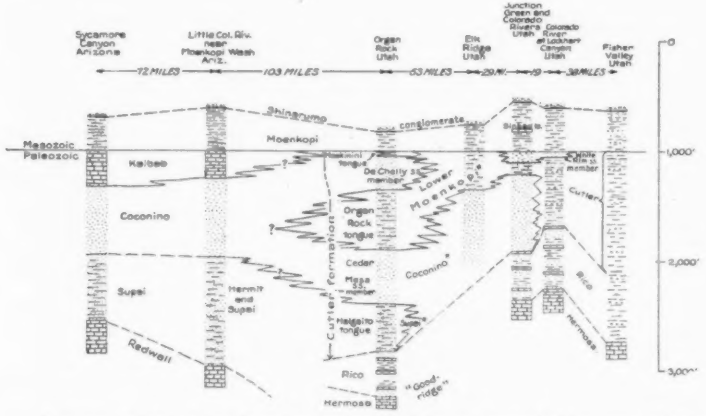

FIG. 3.—Sections from Sycamore Canyon, Arizona, through Monument Valley to Fisher Valley, Utah. Names marked with asterisk (*) are as used in previous reports and are not accepted in this paper.

[1]H. H. Robinson, "The San Franciscan Volcanic Field," *U. S. Geol. Survey Prof. Paper 76* (1913), pp. 22-24.

[2]H. E. Gregory, "Geology of the Navajo Country," *U. S. Geol. Survey Prof. Paper 93* (1917), p. 19.

Along the line of the section the Permian sediments are concealed beneath younger rocks between Little Colorado River, Arizona, and Monument Valley, Utah. Where they appear at the surface in Monument Valley they consist, as described above, of the Rico and Cutler formations, the latter divided into five members. The Rico formation near Organ Rock is 410 feet thick and composed of buff to red sandstones and shales with numerous interbedded fossiliferous marine limestones. The Halgaito tongue of the Cutler formation is red sandstone and sandy shale 430 feet thick. The Cedar Mesa sandstone member, as previously stated, is 500 feet thick, and the Organ Rock tongue about 550 feet thick. The De Chelly sandstone member, the upper of the two light-colored sandstone units, is about 300 feet thick. In the vicinity of Organ Rock the Hoskinini tongue is about 40 feet thick. Northeast from Monument Valley the De Chelly sandstone thins and disappears near San Juan River at Clay Hill Crossing. The upper and middle red beds then merge to form in the region north of San Juan River a single red-bed series that has hitherto been included in the Moenkopi formation.[1] The top of the Permian sediments is marked by an unconformity which separates them from the overlying true Moenkopi of Lower Triassic age. Near the Bears Ears on Elk Ridge the red beds of the upper Cutler are 350 feet thick and consist of deep red to maroon sandstones and sandy mudstones which contrast sharply with the light chocolate-brown shales and flaggy ripple-marked sandstones of the Moenkopi above. Beneath these red beds lies the massive light-colored cross-bedded Cedar Mesa sandstone member forming the broad bench between the Colorado and San Juan rivers. Between San Juan River and the south end of Elk Ridge the Halgaito tongue thins out, and the sandstone thickens until it rests directly on the Rico formation. Instead of the six stratigraphic units recognized in Monument Valley the Permian can be divided into but three units on Elk Ridge—the upper red member of the Cutler formation, the Cedar Mesa sandstone member in the middle, and the Rico formation at the base. This same stratigraphic sequence prevails northeastward to the junction of the Green and Colorado rivers except that the upper red beds thin. The Rico formation is about 600 feet thick, and the Permian sediments above the Rico formation are about 900 feet thick at the junction of Green and Colorado rivers. The upper red beds nearly disappear just north of the junction of the rivers, for a wedge of white sandstone, which has been called the De Chelly(?) or, locally, the

[1] C. R. Longwell and others, "Rock Formations in the Colorado Plateau of Southeastern Utah and Northern Arizona," *U. S. Geol. Survey Prof. Paper 132* (1923), p. 9

White Rim, is present at the top of the Permian, and the Moenkopi formation rests directly on it.[1] The writers believe the name De Chelly should no longer be applied to this sandstone member of the Cutler, but that the current local use of the name White Rim should be formally adopted. A few miles up Colorado River from its junction with Green River the thick Cedar Mesa sandstone member of the Cutler, composing the main body of the Permian sediments, passes completely into deep red or purplish to salmon, coarse-grained, arkosic sandstones with a small amount of shale. The White Rim sandstone extends a little farther but thins northeastward and disappears near the mouth of Lockhart Canyon. The red sediments become coarser-grained and conglomeratic as their outcrop is followed up Colorado River, and at Fisher Valley near the Colorado-Utah state line the conglomeratic maroon sediments are an exact counterpart of the Cutler formation as exposed in the Rico Mountains.[2]

Muddy Mountains, Nevada, across northern Arizona into northwestern New Mexico (*Fig. 4*).—In the Muddy Mountains the limestone, gypsum, shale, and massive sandstones of the Supai formation, nearly 1,500 feet thick, rest on the Callville limestone, of Pennsylvanian age. Above the Supai lie the limestone and gypsum of the Kaibab formation, 450 feet thick, the Coconino sandstone and the Hermit shale not being recognized.

The sections at Bass Trail,[3] Red Canyon,[4] and Little Colorado River[5] are typical Grand Canyon sequences. The Supai as defined by Noble at Bass Trail is 953 feet thick, consisting of red to buff sandstone and red shale with some limestone in the lower 200 feet and resting with slight unconformity on the Redwall limestone. The lower part was formerly included in the Redwall limestone and later transferred to the Supai. It was long assigned to the Pennsylvanian on stratigraphic grounds, but Permian plants occur near the base at Hermit Trail and the entire Supai of that area is now regarded as Permian. There are no definitely proven Penn-

[1]A. A. Baker and others, "Notes on the Stratigraphy of the Moab Region, Utah," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), p. 794.

[2]The section at Fisher Valley shown in Figure 3 was generously supplied by C. H. Dane.

[3]L. F. Noble, "A Section of the Paleozoic Formations of the Grand Canyon at the Bass Trail," *U. S. Geol. Survey Prof. Paper 131* (1922), pp. 26, 29, 59.

[4]Fritz Frech, "Section in Congress Canyon Opposite Point Sublime," *Congrès Géologique International, Compte Rendu de la 5me Session* (1893), pp. 476-81.

[5]H. E. Gregory, "Geology of the Navajo Country," *U. S. Geol. Survey Prof. Paper 93* (1917), p. 19.

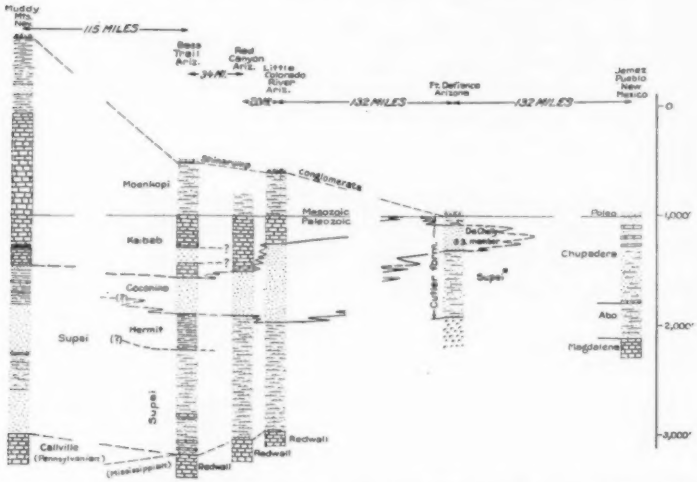

FIG. 4.—Sections from Muddy Mountains, Nevada, to Jemez Pueblo, New Mexico. Names marked with asterisk (*) are as used in previous reports and are not accepted in this paper.

sylvanian beds in the Grand Canyon, and it is not clear where those beds which in near-by regions contain Pennsylvanian fossils make their appearance in the section. The Hermit shale, 332 feet thick at Bass Trail, consists of red sandy shale and soft sandstone. It has not been recognized at many places and the usage of Supai as including beds up to the Coconino still prevails, although beds of Hermit age are probably present in the top. The writers believe there might be an advantage in again including the Hermit shale in the Supai formation as a member with a special type of lithology peculiar to the Grand Canyon region, though the Hermit, where recognized, has been given place as a distinct formation in the diagrams accompanying this paper. The large variety of footprints occurring in both Hermit and Supai, and the fossil floras now known in both, reduce very greatly the importance of the unconformity in the Grand Canyon section.

The Coconino sandstone, 330 feet thick at Bass Trail,[1] consists of a massive, pale buff, cross-bedded sandstone; and the Kaibab limestone, 562 feet thick, of two limestone members separated by buff and reddish

[1] L. F. Noble, "A Section of the Paleozoic Formations of the Grand Canyon at the Bass Trail," *U. S. Geol. Survey Prof. Paper 131* (1923), pp. 26, 28, 66.

sandstone. The sections described at Red Canyon (Congress Canyon), Arizona, by Frech[1] and at Little Colorado River by Gregory[2] closely agree with the Bass Trail section except that the Hermit shale was not recognized, the Cononino is thicker, and the Kaibab correspondingly thinner. Noble[3] says that the Hermit shale is less than 100 feet thick at Tanner Canyon, half-way between Red Canyon and Little Colorado River and that the unconformity at its base is unrecognizable.

Between Little Colorado River near the mouth of Moenkopi Wash and Fort Defiance, Arizona, the Permian strata are concealed by younger sediments. Where the Permian sediments reappear in Bonito Canyon at Fort Defiance they rest upon quartzite of pre-Cambrian age.[4] A little farther to the south, near Hunter Point, the Permian beds rest on granite. The lower part of the Permian consists of red beds, 600 feet thick, called Moenkopi by Gregory[5] and Supai by Hager[6] and Darton.[7] In them Gregory found fossil plants determined by David White[8] to be of Permian age.

Upon the red beds above the pre-Cambrian lies a massive sandstone more than 250 feet thick and continuous with the De Chelly sandstone of De Chelly Canyon. The writers agree with Darton and Hager[9] that this sandstone at Fort Defiance is probably continuous under the intervening younger beds with the Coconino sandstone of the Holbrook, Arizona, region, where a thin remnant of Kaibab limestone is still observable.

At Fort Defiance the Kaibab limestone is absent and the uppermost Permian strata are interbedded red shale and thin buff to salmon-colored, massive, irregularly bedded sandstones, in all 80 feet thick, that are not sharply separated from the underlying massive sandstone, but whose top is a marked erosional unconformity separating them from the overlying Shinarump conglomerate. This series of beds has been included

[1]Fritz Frech, *loc. cit.*

[2]H. E. Gregory, *loc. cit.*

[3]L. F. Noble, *op. cit.*, pp. 64, 65.

[4]H. E. Gregory, *op. cit.*, pp. 17, 27.

[5]*Ibid.*, p. 27.

[6]Dorsey Hager, "Stratigraphy—Northeast Arizona-Southeast Utah," *Mining and Oil Bull.*, Vol. 10 (1924), pp. 167, 423.

[7]N. H. Darton, "A Résumé of Arizona Geology," *Univ. of Arizona Bull. 119* (1925), pp. 85, 91, 207, Pl. 61 b.

[8]H. E. Gregory, *ibid.*, p. 31.

[9]N. H. Darton, *ibid.*, p. 207. Dorsey Hager, *ibid.*, pp. 176, 423.

in the Moenkopi formation by Darton,[1] but the writers believe that they should be included in the Permian, since they show none of the easily recognizable characteristics of the Moenkopi formation and are not sharply separated from the underlying massive sandstone. The only unconformity apparent is at the base of the Shinarump conglomerate, and this unconformity may well represent, as it does at various places north of Fort Defiance, the remainder of Permian time and Triassic time to the beginning of the Shinarump.

At Fort Defiance the Permian strata dip under younger strata in the Defiance monocline to reappear at the surface, on the line of the section, at Jemez Pueblo, New Mexico. The stratigraphic succession and lithology are somewhat different here, and different stratigraphic names have been applied. The Permian formations, Chupadera above and Abo below, constituting the Manzano group, rest on the Magdalena limestone, of Pennsylvanian age.[2] The writers did not visit this locality, but from Renick's description of the formations it seems likely that the De Chelly sandstone, as a lithologic unit, disappears eastward, although Darton[3] says "it reappears again extensively in New Mexico as part of the Chupadera formation." Part of the Chupadera formation is probably the time equivalent of the De Chelly or Coconino sandstones, but it would seem difficult to pick out a lithologic unit in the Chupadera formation as equivalent to the notably variable De Chelly or Coconino sandstones. The precise equivalency in time or lithology between the section at Fort Defiance and that at Jemez Pueblo can not be stated at the present time. Limestones in the Chupadera have at places yielded invertebrates like those of the Kaibab, and the Abo sandstone has yielded Permian plants. Difference of opinion prevails as to the age of invertebrates in the lower Abo. Upper Triassic vertebrates occur at some places below the Poleo sandstone,[4] indicating that the Poleo sandstone and some part of the underlying beds are younger than Permian and that the Poleo sandstone is younger than Shinarump conglomerate. In Figure 4 the base of the Shinarump conglomerate should possibly be correlated with some horizon in the interval labeled on the section as the Chupadera

[1]N. H. Darton, "A Résumé of Arizona Geology," *Univ. of Arizona Bull. 119* (1925), p. 110.

[2]B. C. Renick, "Western Sandoval County, New Mexico," *U. S. Geol. Survey Water Supply Paper* (in press).

[3]N. H. Darton, *ibid.*, p. 91.

[4]E. C. Case, "Contributions from the Museum of Paleontology, Univ. of Michigan," Vol. 3, No. 1 (1928).

formation, although Darton[1] considers the beds below the Poleo near Jemez to be all Permian.

Sycamore Canyon, Arizona, to Jemez Pueblo, New Mexico (Fig. 5).—This section extends nearly east-west across the southern margin of the region discussed in this paper and connects the section of Grand Canyon type with that of the Zuni Mountains. At Sycamore Canyon, Arizona,[2] and Chevelon Creek, Arizona,[3] the Permian units resemble those of the Grand Canyon. The red beds of the Supai formation are 600 feet thick at Sycamore Canyon and 1,050 to 1,200 feet thick in drill holes near Chevelon Creek,[4] resting on Redwall limestone. The Hermit shale has not been identified. At both of these localities the Coconino sandstone is about 600 feet thick. The Kaibab limestone thins eastward from more than 300 feet at Sycamore Canyon to about 100 feet at Chevelon Creek and disappears a short distance east of Chevelon Creek. Upon the Kaibab limestone rests unconformably the Moenkopi formation, of Lower Triassic age, unconformably overlain by the Shinarump conglomerate.

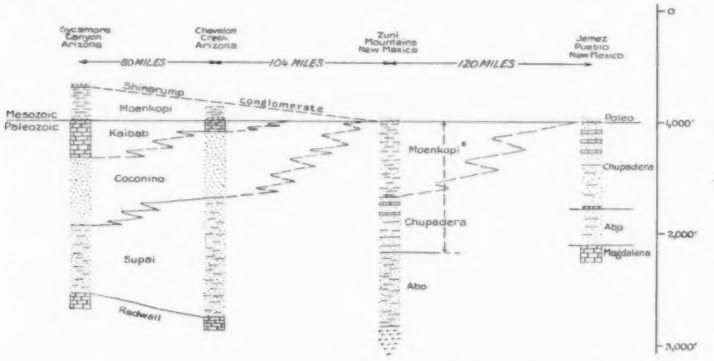

FIG. 5.—Sections from Sycamore Canyon, Arizona, to Jemez Pueblo, New Mexico. Names marked with asterisk (*) are as used in previous reports and are not accepted in this paper.

[1]N. H. Darton, "'Red Beds' and Associated Formations in New Mexico," *U. S. Geol. Survey Bull. 794* (1928), p. 157.

[2]H. H. Robinson, "The San Franciscan Volcanic Field, Arizona," *U. S. Geol. Survey Prof. Paper 76* (1913), pp. 22-24.

[3]N. H. Darton, "A Résumé of Arizona Geology," *Univ. of Arizona Bull. 119* (1925), pp. 96, 203.

[4]N. H. Darton, *ibid.*, p. 203.

One hundred miles east of the Chevelon Creek locality the Permian strata reappear from beneath a cover of younger strata in the Zuni Mountain uplift in New Mexico. Darton[1] has described the Permian sediments as constituting the Manzano group, with the Chupadera formation above and the Abo sandstone below, resting on pre-Cambrian granite. The Abo sandstone is 600-700 feet thick and is composed of brown-red slabby sandstone and sandy shale with some limestone. The Chupadera formation is 500 feet thick and is composed of limestone and hard gray sandstone above and soft red sandstone below. Above the Chupadera formation are 500-850 feet of shale, mostly sandy and red, that has been assigned by Darton to the Moenkopi formation. All the evidence known to the writers indicates that the true Moenkopi formation is thinning eastward, and since it is absent at Fort Defiance, Canyon De Chelly, and practically so on the east side of Monument Valley, it seems unlikely that the Moenkopi formation would, at a point east of Fort Defiance, have so great a thickness. It seems, on the other hand, quite likely, in view of known changes in the lithology of Permian sediments, that most or all of the red beds included by Darton in the Moenkopi formation in the Zuni Mountain uplift should be included in the Permian, and they are so indicated on the diagram. The occurrence at several localities of Permian vertebrates[2] in red beds in or above the Chupadera is strongly in favor of this view. The contact between the Triassic and the Permian would then be at the base of the Shinarump conglomerate, as it is at Fort Defiance and Canyon De Chelly. The lithologic units differentiated in the Permian farther west are not recognizable in the Permian sediments of the Zuni Mountain uplift, though part of the Chupadera bears a fauna much like that of the Kaibab limestone. Probably there was a connection south of the area dealt with in this paper by which the Kaibab and Chupadera faunas could mingle.

The section at Jemez Pueblo described in the discussion of Figure 4 is given on Figure 5 for purposes of comparison.

Circle Cliffs, Utah, southeast to Zuni Mountains, New Mexico (Fig. 6).—This cross section connects the section of Grand Canyon type through Monument Valley with the section in the Zuni Mountains. At Circle

[1] N. H. Darton, "Geologic Structure of Parts of New Mexico," *U. S. Geol. Survey Bull. 726* (1922), pp. 31, 36, 44; and "'Red Beds' and Associated Formations in New Mexico," *U. S. Geol. Survey Bull. 794* (1928), pp. 137-55.

[2] E. C. Case, "Further Evidence Bearing on the Age of the Red Beds in the Rio Grande Valley," *Science*, new ser., Vol. 44 (1916), p. 709. N. H. Darton, "'Red Beds' and Associated Formations in New Mexico," *U. S. Geol. Survey Bull. 794* (1928), pp. 26, 29.

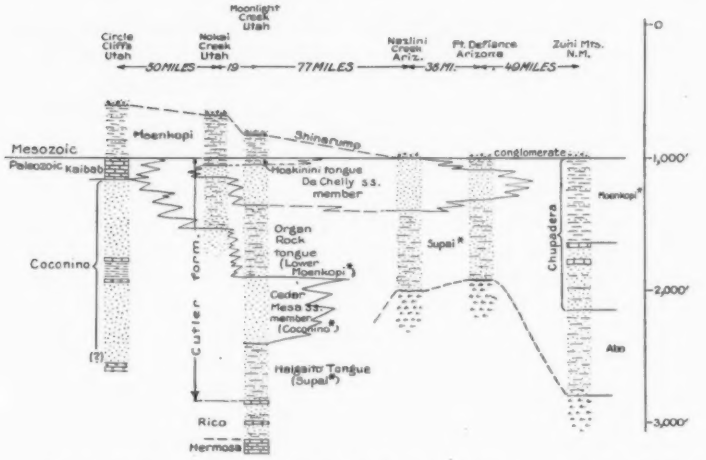

FIG. 6.—Sections from Circle Cliffs, Utah, through Monument Valley to Zuni Mountains, New Mexico. Names marked with asterisk (*) are as used in previous reports and are not accepted in this paper.

Cliffs, Utah, the Permian strata are known chiefly from the log of a single well. Gregory[1] and Moore describe about 150 feet of Kaibab limestone, beneath which are light-colored sandstones more than 1,200 feet thick, with about 200 feet of limestone and shale near the middle. All of this thick series of sandstones is probably to be assigned to the Coconino sandstone.

Permian strata are not exposed for some distance southeast of Circle Cliffs, but in Monument Valley the complete section described on pages 1420-1423 is exposed. Where they first appear, in the Balanced Rock anticline at the mouth of Nokai Creek, only the upper 600 feet of the Cutler formation is exposed. About 50 feet of the white Cedar Mesa sandstone member shows above the water level of San Juan River. Above it are 400 feet of red beds constituting the Organ Rock tongue, then the De Chelly sandstone member, less than 100 feet thick in Balanced Rock anticline and so stained by wash from the overlying red beds that it is not a conspicuous unit. It thins out completely near Clay Hill Crossing, a few miles east of the Balanced Rock anticline, and is shown in the diagram as thinning out to the northwest, though it may possibly be continuous under cover with the Coconino sandstone. About 50 feet of red

[1]H. E. Gregory and R. C. Moore, "Kaiparowits Region, Utah-Arizona," *U. S Geol. Survey Prof. Paper* (in press).

sandy shales, sandy mudstones, and sandstones at the top of the Permian constitute the Hoskinini tongue of the Cutler formation. Near Moonlight Creek and Organ Rock the entire series of Permian beds, as stated on pages 1422-1425, is displayed. The underlying rock is Hermosa (Pennsylvanian) limestone. The Rico formation (basal Permian) is 300 feet thick, and the basal Halgaito tongue of the Cutler is 425 feet thick. The Cedar Mesa sandstone is about 500 feet thick. East of the line of the cross section this sandstone may be observed to change southeastward into red sandy shales and sandstones. On the line of cross section an interval of 70 miles southeast of Monument Valley is covered, but the same sort of change must occur and is so shown. Above the Cedar Mesa sandstone the Organ Rock tongue is 500 feet thick. At the northeast point of Hoskinini Mesa there is a local irregularity at the contact between the Organ Rock tongue and the overlying De Chelly sandstone, the red beds abruptly rising for a short distance along the outcrop some 50 feet into the overlying sandstone. This is the only irregularity observed at the contact, and the writers believe it to be a depositional and not an erosional feature. The De Chelly sandstone member thickens rapidly to the southeast from Nokai Creek and is 300 feet thick on Moonlight Creek. The Hoskinini tongue observed at the mouth of Nokai Creek is still present on Moonlight Creek, but is thinning out toward the southeast.

Southeast of Monument Valley along the line of the section shown in Figure 6 the next Permian exposures are in the Defiance uplift. Here a complete section is not present, for the Permian strata overlap as previously stated, on pre-Cambrian granite and quartzite. A well at Nazlini Creek, near Chinle, Arizona,[1] showed the De Chelly sandstone member to be about 400 feet thick, the upper 200 feet exposed, underlain by 600 feet of red beds, and then granite. In the walls of the near-by Canyon De Chelly an incomplete exposure of the De Chelly member shows a thickness of about 800 feet, with the Shinarump conglomerate, of Upper(?) Triassic age, resting directly upon it. There should be red beds beneath it, in all probability, but no data are available. In Bonito Canyon, west of Fort Defiance and about 36 miles southeast of Canyon De Chelly, the Permian strata are similar to those known at Nazlini Creek. Beneath the Shinarump conglomerate lies the 80 feet of red beds which the writers include in the Permian. The underlying De Chelly sandstone is about 260 feet thick and obviously continuous with the De Chelly sandstone of De Chelly Canyon and Nazlini Creek. It is in turn

[1] N. H. Darton, "A Résumé of Arizona Geology," *Univ. of Arizona Bull. 119* (1925), p. 86.

underlain by about 600 feet of red sandy shales, sandy mudstones, and sandstone, which rest on the pre-Cambrian quartzite.

Fifty miles southeast of Fort Defiance, in the Zuni Mountain uplift in New Mexico, Permian sediments reappear on the line of cross section after dipping under younger beds on the east flank of the Defiance monocline. These Permian rocks were described in the discussion of Figure 5. The Shinarump conglomerate rests unconformably upon red beds 600 feet or more thick which the writers assign to the Permian. The underlying Chupadera and Abo formations, which together are nearly 1,200 feet thick in the Zuni Mountains, would then be the time equivalent of the lower part of the Permian strata found northwest of Canyon De Chelly. The Abo formation rests on pre-Cambrian granite, and marine fossils of Kaibab aspect in the Chupadera suggest a connection by some southern route with the Kaibab marine sediments.

Jerome district, Arizona, to the San Rafael Swell, Utah (Fig. 7).—The six columnar sections shown in this cross section are all located in the area where the succession of Permian strata is like that of the Grand Canyon, and are all divisible into three units: red beds in the lower part, Coconino sandstone in the middle, and Kaibab limestone at the top.

In the Jerome district Ransome[1] described Coconino sandstone, 500 feet thick, resting upon the Supai formation, 1,000 feet thick. The Hermit shale was not recognized, and the Kaibab limestone has been eroded off. At Sycamore Canyon Robinson[2] found red sandstone and shale of the Supai formation, 600 feet thick, resting upon Redwall limestone; upon the Supai formation, the Coconino sandstone, also about 600 feet thick; and at the top the Kaibab limestone, about 325 feet thick and separated from the Lower Triassic Moenkopi by an unconformity. The Hermit shale was not recognized.

Frech[3] briefly described the Permian stratigraphy at Red Canyon (then Congress Canyon) in the Grand Canyon district. The lower 1,000 feet of the Permian sediments consists of red sandstones and shales of the Supai formation and Hermit shale. Upon them lies the Coconino sandstone, 400 feet thick, and the Kaibab limestone, 500 feet thick.

From the Grand Canyon district northeastward the Kaibab limestone thins. The thinning of the limestone, the writers believe, is due

[1]F. L. Ransome, "Some Paleozoic Sections in Arizona and their Correlation," *U. S. Geol. Survey Prof. Paper 98* (1917), Pl. 25.

[2]H. H. Robinson, "The San Franciscan Volcanic Field," *U. S. Geol. Survey Prof. Paper 76* (1913), pp. 22-24.

[3]F. Frech, "Section in Congress Canyon opposite Point Sublime," *Congrès Géologique International, Compte Rendu de la 5me Session* (1893), pp. 476-81.

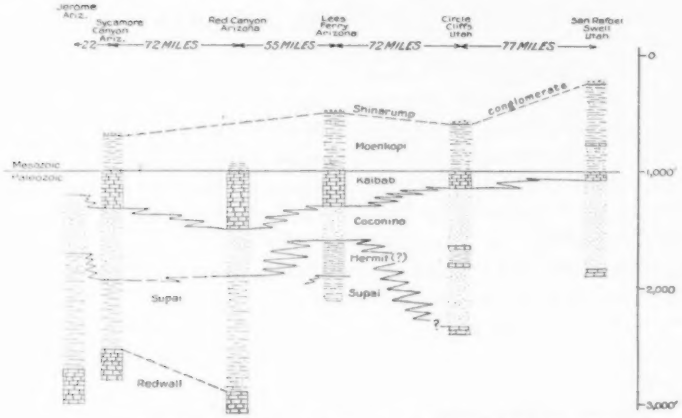

FIG. 7—Sections from Jerome, Arizona, to San Rafael Swell, Utah.

to a lateral gradation of the lower part of the limestone into calcareous sandstone, a feature which makes it difficult to determine a boundary between the Kaibab limestone and the Coconino sandstone at some localities and which has led geologists to give differing figures for the thickness of the Kaibab and the Coconino sandstone. This is the condition at Lees Ferry, where Bryan[1] and Moore[2] assign different thicknesses to the two units but agree on the combined thickness as about 650 feet. The writers' interpretation of the section agrees with that of Bryan. Between the base of the Coconino sandstone and the water level of Colorado River there are exposed about 500 feet of red sandstones and shales which include possibly the Hermit shale and part of the Supai formation.

Northeast of Lees Ferry, Arizona, the upper part of the Permian sediments is exposed on the line of the section in Circle Cliffs, Utah, and in the San Rafael Swell, Utah. The correlation from Lees Ferry northeastward must be made with reference to the Kaibab limestone. At Circle Cliffs the Kaibab limestone is 160 feet thick, and at San Rafael Swell it has thinned to 80 feet and is discontinuous. Gilluly and Reeside[3]

[1]Kirk Bryan, cited by C. R. Longwell and others in "Rock Formations in the Colorado Plateau of Southeastern Utah and Northern Arizona," *U. S. Geol. Survey Prof. Paper 132* (1923), p. 16.

[2]R. C. Moore in H. E. Gregory and R. C. Moore's "Kaiparowits Region, Utah-Arizona," *U. S. Geol. Survey Prof. Paper* (in press).

[3]James Gilluly and J. B. Reeside, Jr., "Sedimentary Rocks of the San Rafael Swell and Some Adjacent Areas in Eastern Utah," *U. S. Geol. Survey Prof. Paper 150* (1928), p. 64.

state, on the authority of Girty, that the Kaibab limestone of the San Rafael Swell is equivalent to uppermost Kaibab ("Bellerophon" limestone) of the type locality. Gilbert,[1] in his description of the Henry Mountains, a few miles east of the line of the section, does not record any limestone above the Coconino sandstone. In Circle Cliffs 160 feet of Kaibab limestone rests on nearly 1,200 feet of white sandstone with about 200 feet of limestone and shale near the middle, all of it probably to be assigned to the Coconino sandstone. In the San Rafael Swell the oldest rocks exposed are white to buff, massive sandstones 715 feet thick and containing much limestone in the lowest 40 feet. These rocks are correlated with the Coconino sandstone by Gilluly and Reeside. The log of a well[2] drilled in the Swell shows much more limestone and much less red rock than would be expected and is difficult to interpret in terms of the nearest exposures. There is some suggestion, however, that the limestone in the middle of the Coconino of Circle Cliffs is to be correlated with the limestone at the base of the exposures in San Rafael Swell.

Nazlini Creek and Canyon De Chelly, Arizona, to the junction of Green and Colorado rivers, Utah (*Fig. 8*).—The line of this cross section is approximately parallel with, and east of, the line marking the eastern limit of the Kaibab limestone. All the sections are in the zone where Permian sediments are composed of interbedded red beds and massive light-colored sandstones, and the line of the cross section is at right angles to the direction of the major changes in the lithology, though including some striking lesser changes. At Canyon De Chelly the Shinarump conglomerate rests on 800 feet of the De Chelly sandstone member of the Cutler formation with the base not exposed. At Nazlini Creek the Cutler formation includes the De Chelly, only 400 feet thick, however, and 600 feet of red sandy shale resting on red granite of pre-Cambrian age. In Gypsum Creek an unbroken series of red sandy shales and sandstones, 1,500 feet thick and constituting most of the Cutler formation, rests on the red sandstones and shales and the marine limestones of the Rico formation, about 350 feet thick. The De Chelly sandstone member of the Cutler is about 550 feet thick in Gypsum Creek, but it thins northward rapidly, is 100 feet thick where Comb Ridge crosses San Juan River, and disappears entirely a short distance north of the river. Northward from Gypsum Creek and in the canyon of San Juan River a complete section of Permian strata is exposed. The Rico formation is 300-350

[1]G. K. Gilbert, "Geology of the Henry Mountains," *U. S. Geog. and Geol. Survey of the Rocky Mountain Region* (1877).

[2]James Gilluly, "Geology and Oil and Gas Prospects of Part of the San Rafael Swell, Utah," *U. S. Geol. Survey Bull. 806* (1929), p. 129.

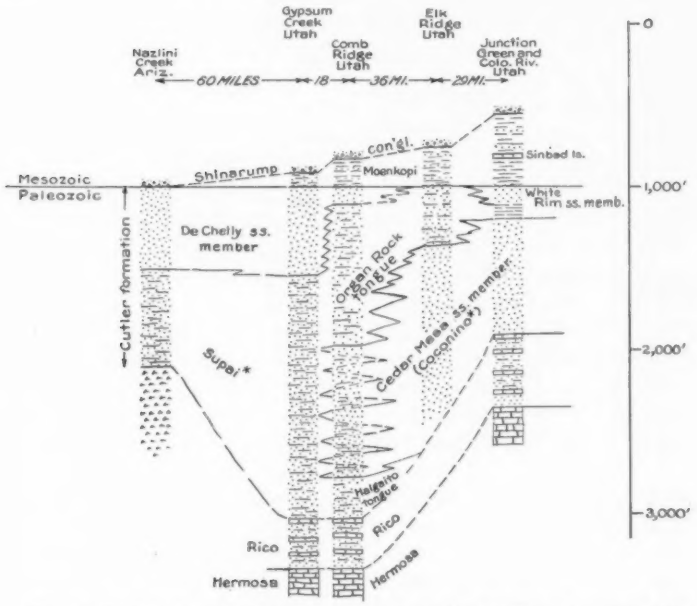

FIG. 8.—Sections from Nazlini Creek, Arizona, to the junction of Green and Colorado rivers. Names marked with asterisk (*) are as used in previous reports and are not accepted in this paper.

feet thick and rests on the Pennsylvanian Hermosa limestone. Above it are 1,900 feet of red sandy shales and sandstones similar to those of the Cutler formation in Gypsum Creek. In the midst of these red beds appears a series of muddy, brownish-yellow, massive, soft sandstones interbedded with gypsiferous shale, beds of white gypsum as much as 50 feet thick, and some thin beds of cherty limestone. This sandy and gypsiferous zone, inconspicuous in a casual examination of the outcrop, is clearly the southeastern edge of the Cedar Mesa sandstone member, and the complete passage from red beds to light-colored sandstone may be seen from a single viewpoint. This gypsiferous and sandy series at Comb Ridge is about 800 feet thick. Between the base of this series and the uppermost marine limestone of the Rico formation are red shales and sandstones 250 feet thick, the relatively thin extension of the Halgaito tongue. Above the gypsiferous series are red beds about 800 feet thick, the beginning of the Organ Rock tongue, and, as stated above, a thin remnant of De Chelly sandstone.

On Elk Ridge near the Bears Ears the De Chelly sandstone is absent, and the uppermost Cutler beds are red sandy mudstones, shales, and sandstones 350 feet thick, separated from the overlying red shales of the Moenkopi formation by an unconformity and resting on the Cedar Mesa sandstone member. The writers have no measurement of the thickness of the Cedar Mesa member at this locality, but it must be nearly 1,000 feet thick. A few miles north of the Bears Ears in Dark Canyon this member rests directly upon marine limestone of the Rico formation, the Halgaito tongue of the Cutler having passed into the basal part of the Cedar Mesa member. Thirty miles north of the Bears Ears, at the junction of Green and Colorado rivers, the Permian strata are thinner. The Rico formation is 600 feet thick and is overlain by massive sandstones 900 feet thick, buff to white with indefinite bands of pink, and regularly bedded in very thick units which are cross-bedded. As noted in the discussion of Figure 3, the white sandstone passes entirely into red beds a few miles northeast of the junction of the rivers. A short distance northeast of the junction of the rivers the uppermost 100 feet of the section is the White Rim sandstone member of the Cutler, and just beneath it coarse-grained, red to purple arkosic sandstones with some shale, 100 feet thick.

Composite correlation diagram (*Fig. 9*).—This diagram attempts to show in perspective the variations in Permian stratigraphy, and serves to bring together into one picture the data given in the diverse cross-sections presented in Figures 2-8. To gain simplicity the minimum number of symbols has been used. All the massive, light-colored, cross-bedded sandstones differentiated in the various sections are shown by the same standard sandstone symbol. All red beds, regardless of whether they are sandstone or shale, are shown by the standard shale symbol. Limestones are shown in the usual way, and all pre-Cambrian rocks are shown by the symbol for igneous rocks. No attempt is made to distinguish between observed and inferred conditions. The upper surface of the stereogram represents the Permian-Triassic boundary as a plane and is the datum. The vertical height of the strips is 2,500 feet throughout and all thicknesses are plotted proportionately.

The Kaibab limestone becomes progressively thinner from Muddy Mountains (*MM*) and the St. George region (*SG*) eastward to the Bass Trail (*BT*), Circle Cliffs (*CC*), and Flagstaff (*FL*), disappearing near San Rafael Swell (*SR*), west of Monument Valley (*MV*), and near Holbrook (*HB*). Below the Kaibab limestone the variation in the Permian sediments is less regular except that in general the massive, cross-bedded,

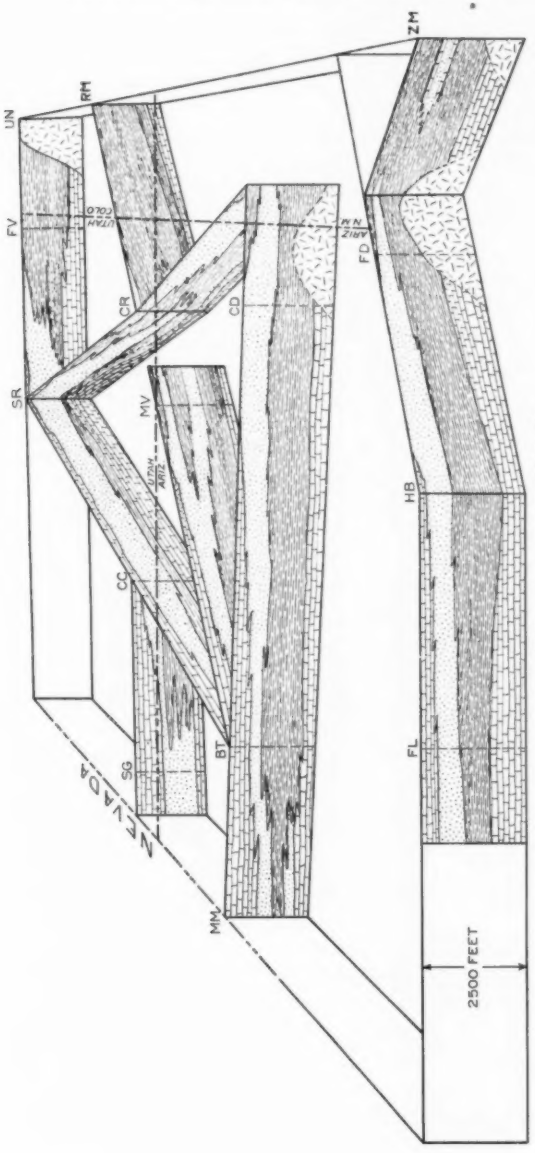

FIG. 9.—Composite correlation diagram, showing in perspective the relations of the Permian deposits of northern Arizona, southern Utah, southwestern Colorado, and northwestern New Mexico.

light-colored sandstones grade into red beds from the west toward the east, and that the red beds, conversely, are at a maximum in the east and pass into non-red beds westward. The maximum thickness of the light-colored sandstones is in the northwest, except for the observed maximum at Canyon De Chelly (*CD*). The red beds are at their maximum in southwestern Colorado. The massive limestone beds at the base of the sections are not differentiated as to age. At most places they are Pennsylvanian, at some they are Mississippian, but they serve to show the base of the Permian. The red beds of the Permian overlap on pre-Cambrian at three localities shown—Uncompahgre Plateau (*UN*), Fort Defiance (*FD*), and at Nazlini Creek near Canyon De Chelly (*CD*). Three other places indicated are Fisher Valley (*FV*), Comb Ridge (*CR*), and Zuni Mountains (*ZM*).

NOMENCLATURE

The nomenclature applied to the Permian formations in the regions adjacent to the Grand Canyon and in southwestern Colorado was fairly well stabilized about twenty years ago. On the contrary, that applied to the intermediate region extending from Fort Defiance northward through Monument Valley to the Moab district has been much confused, chiefly because few, if any, of those dealing with the stratigraphy of the region have had opportunity to follow the stratigraphic units over more than a small part of it.

Grand Canyon region.—Darton[1] in 1910 substituted for the names of the subdivisions of the Aubrey group used by the earlier students in the Grand Canyon region ("Lower Aubrey" sandstone, "Upper Aubrey" sandstone, and "Aubrey" limestone) the names Supai formation, Coconino sandstone, and Kaibab limestone. These stood until Noble[2] in 1922 redefined Supai by separating from it as an overlying unit in the Grand Canyon the Hermit shale, and by adding to it a lower member of supposed Pennsylvanian limestones formerly included in the Redwall limestone, but separated from the rest of the Redwall by an unconformity. These limestones have not yielded any invertebrates in the Grand Canyon region, but on the other hand the basal Supai at Hermit Trail has furnished Permian plants. What relation to the strata of the Grand Canyon the beds in other regions may bear that do contain Pennsylvanian fossils is not yet determined, nor has the presence or absence of

[1]N. H. Darton, "A Reconnaissance of Parts of Northwestern New Mexico and Northern Arizona," *U. S. Geol. Survey Bull. 435* (1910), pp. 25, 27, 28.

[2]L. F. Noble, "A Section of the Paleozoic Formations of the Grand Canyon at the Bass Trail," *U. S. Geol. Survey Prof. Paper 131* (1922), pp. 59, 64.

Pennsylvanian in the Grand Canyon as a whole been finally determined. At many places the Hermit shale has not been recognized as distinct from the Supai, though in the Grand Canyon itself it is unconformable on the Supai. The Supai, Hermit, and Coconino formations have yielded many footprints described chiefly by Gilmore;[1] the basal Supai has yielded early lower Permian, and the Hermit shale later Permian plants;[2] the Kaibab formation has yielded a large fauna of marine invertebrates. For many years the Kaibab fauna was assigned to the Pennsylvanian and that of the overlying Moenkopi formation to the Permian, but in recent years the Kaibab fauna has been placed in the Permian and the Moenkopi fauna in the Lower Triassic.

Southwestern Colorado.—Cross[3] and his assistants several decades ago applied in southwestern Colorado the names ever since accepted for the Permian—Rico and Cutler formations. The Rico fauna[4] was first considered transitional between Pennsylvanian and Permian, then for years it was assigned to the Pennsylvanian, but in recent years it has been definitely assigned to the Permian. The Cutler has not yielded fossils but is assigned to the Permian because of its position and relation to the enclosing formations.

Monument Valley and the country north and south from it.—In the region between that where the Grand Canyon names can be used to advantage and that where the Colorado names can be used, the stratigraphy is somewhat involved and the nomenclature correspondingly tangled. The more important areas, both because of the stratigraphic details observable and the more extensive literature dealing with them, are in Monument Valley and near Moab, Utah.

For Monument Valley, Figure 10 shows in compact form the nomenclatures that have been used and the relations between them. In the earlier work some local names were introduced, but mostly the investi-

[1]C. W. Gilmore, "Fossil Footprints from the Grand Canyon," *Smithsonian Misc. Coll.*, Vol. 77, No. 9 (1926); "Fossil Footprints from the Grand Canyon: Second Contribution," *ibid.*, Vol. 80, No. 3 (1927); "Fossil Footprints from the Grand Canyon: Third Contribution," *ibid.*, Vol. 80, No. 8 (1928).

[2]David White, personal communication.

[3]Whitman Cross and A. C. Spencer, "Geology of the Rico Mountains, Colorado," *U. S. Geol. Survey 21st Ann. Rept.*, Pt. 2 (1900), pp. 59-66.
Whitman Cross and Ernest Howe, "Red Beds of Southwestern Colorado and Their Correlation," *Bull. Geol. Soc. Amer.*, Vol. 16 (1905), p. 461.
Whitman Cross and others, many folios of U. S. Geol. Survey Geol. Atlas in southwestern Colorado.

[4]G. H. Girty, "The Carboniferous Formations and Faunas of Colorado," *U. S. Geol. Survey Prof. Paper 16* (1903), pp. 252-53. Various folios of U. S. Geol. Survey Geol. Atlas in southwestern Colorado.

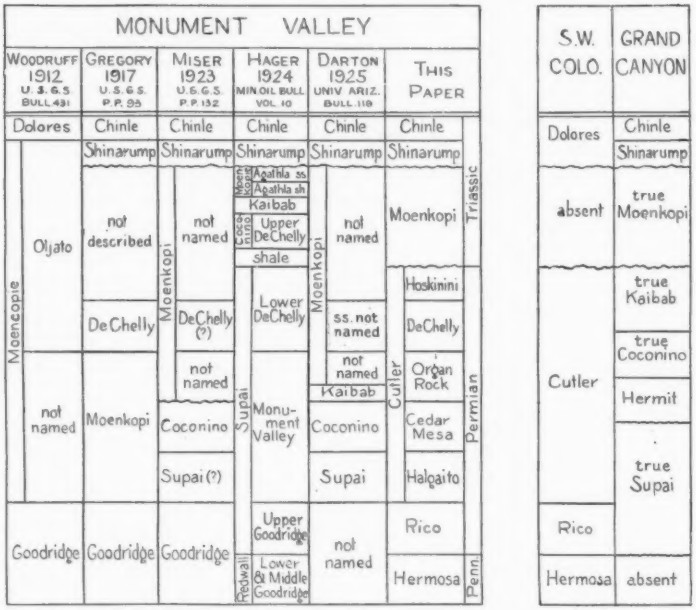

FIG. 10.—Nomenclature in Monument Valley, Utah. That of southwestern Colorado and Grand Canyon region shown for comparison.

gators believed they could recognize units accepted elsewhere and the appropriate names were applied. Even where the same names were used, however, differing interpretations of the relationships of the rocks led to discordant concepts of what the names meant in the local sections.

Woodruff[1] was the first to apply a modern terminology to the formations, though Gregory[2] had described the rocks briefly a year earlier without using formation names. Woodruff used "Goodridge" for all of the interval containing fossiliferous marine limestones; Moencopie (=Moenkopi) for the overlying red beds, differentiating the "Oljato sandstone member" at the top; and Dolores for the overlying Triassic beds (Chinle of later writers).

[1]E. G. Woodruff, "Geology of the San Juan Oil Field, Utah," *U. S. Geol. Survey Bull. 471* (1912), pp. 76-90.

[2]H. E. Gregory, "The San Juan Oil Field, San Juan County, Utah," *U. S. Geol. Survey Bull. 431* (1911), pp. 11-25.

Gregory[1] in 1917 accepted Woodruff's "Goodridge" and part of his Moenkopi, discarding, however, the "Oljato sandstone" and substituting for the lower and upper parts of it the new term De Chelly sandstone and the older term Shinarump conglomerate. The section then included Goodridge, Moenkopi, De Chelly, with Triassic Shinarump above.

Miser[2] in 1923 and 1924 in three papers gave a description of the section, modifying considerably the previous nomenclature and recognizing in the main the units accepted in the present paper. He adopted "Goodridge," applied Supai(?) to a red-bed unit just above the "Goodridge," and Coconino to an overlying sandstone. Neither of these units had been clearly distinguished by Woodruff or Gregory. Hermit shale he did not recognize definitely and Kaibab limestone he considered absent through erosion. Above the Coconino he recognized an unconformable Triassic Moenkopi formation containing the De Chelly(?) sandstone lentil near its middle, and then next above, the Shinarump conglomerate.

In 1924 Hager[3] offered a quite different terminology. He divided "Goodridge" into lower, middle, and upper parts, suggesting that the lower two are Redwall and the upper part is lower Supai. Above it he named a "Monument Valley shale," referring it to the middle Supai. Next above he recognized a "Lower De Chelly," referring it to the upper Supai, and an "Upper De Chelly," which he considered Coconino. The overlying rocks he divided into Kaibab limestone, Agathla shale, and Agathla sandstone, the latter two being new names and together equivalent to Moenkopi. Next above he recognized Shinarump conglomerate. It is somewhat difficult to interpret on the ground exactly what units are meant by Hager's names, though probably his "upper Goodridge" is Rico; his "Monument Valley shale" extends from the top of the "Goodridge" to the base of the De Chelly of Gregory; his "Lower De Chelly" is Gregory's De Chelly; and his "Upper De Chelly," Kaibab, Agathla shale and Agathla sandstone, all thin units, together are the

[1]H. E. Gregory, "Geology of the Navajo Country," *U. S. Geol. Survey Prof. Paper 93* (1917), pp. 20, 29, 32.

[2]H. D. Miser, quoted by C. R. Longwell and others, "Rock Formations in the Colorado Plateau of Southeastern Utah and Northern Arizona," *U. S. Geol. Survey Prof. Paper 132* (1923), pp. 5-10, Pls. 2, 3; "The San Juan Canyon, Southeastern Utah," *U. S. Geol. Survey Water Supply Paper 538* (1924), pp. 33-37; "Geologic Structure of San Juan Canyon and Adjacent Country, Utah," *U. S. Geol. Survey Bull. 751* (1924), pp. 119-23.

[3]Dorsey Hager, "Stratigraphy—Northeast Arizona-Southeast Utah," *Mining and Oil Bulletin*, Vol. 10 (1924), pp. 137, 383, 423.

upper Moenkopi of Miser. Hager seems not to have separated the Coconino of Miser from his "Monument Valley shale."

Darton[1] in 1925 called the lower red beds Supai and the overlying sandstone Coconino, supposing it to be identical with the De Chelly of Gregory. He recognized a very thin Kaibab limestone above his Coconino. The overlying beds he called Moenkopi, identifying the sandstone in their midst as part of the "Oljeto sandstone member" of Woodruff. Next above he recognized Shinarump conglomerate. There is some confusion in Darton's application of the name Coconino, but it is probable that he intended it to apply as stated in this paragraph.

In the present paper the writers are abandoning the attempt to apply a Grand Canyon nomenclature in Monument Valley, and are introducing for the larger units the names used in the San Jaun Mountain region: Hermosa and Rico formations to replace "Goodridge," and Cutler formation for the interval from the top of the "Goodridge" to the unconformity at the base of the Lower Triassic Moenkopi formation. Within the Cutler formation five members are here given names: (1) Halgaito tongue at the base, from Halgaito Spring, southwest of Mexican Hat, Utah, near which the unit is well displayed; (2) Cedar Mesa sandstone member, for the unit called Coconino by Miser and Darton, but apparently not noted by Woodruff, Gregory, and Hager, the name being from Cedar Mesa, on San Juan River west of Mexican Hat, where the beds are well exposed; (3) Organ Rock tongue, for the red beds assigned to the lower Moenkopi by Miser and Darton and forming the upper part of the Moenkopi of Gregory and of the "Monument Valley shale" of Hager, the name being derived from the fact that the beds compose the natural monument known as Organ Rock, lying south of San Juan River between Moonlight and Copper creeks; (4) De Chelly sandstone member, accepting that name as applied by Gregory to part of Woodruff's "Oljato sandstone," which is Miser's De Chelly(?) sandstone lentil and Hager's "Lower De Chelly;" (5) Hoskinini tongue, for the relatively thin red-bed unit above the De Chelly sandstone and beneath the Moenkopi, the name being derived from the exposures on the north face of Hoskinini Mesa, several miles west of Oljeto trading post on Moonlight Wash.

In the region south of Monument Valley the Cedar Mesa sandstone has passed into red beds and the three lower members of the Cutler become one red-bed unit overlain by the De Chelly member. At places a thin red-bed unit lies above this, as at Fort Defiance. This succession

[1] N. H. Darton, "A Résumé of Arizona Geology," *Univ. of Arizona Bull. 119* (1925), pp. 94, 110, 207; Pls. 17b, 25c, 61a.

was called Moenkopi and De Chelly by Gregory;[1] Supai, Coconino, and Moenkopi by Hager[2] and Darton,[3] though in much earlier work Darton[4] had called it Triassic red beds and Wingate sandstone.

Northward from Monument Valley, Miser, Longwell, and Paige[5] used in 1923 for the region between Colorado and San Juan rivers the nomenclature applied by Miser to Monument Valley—Goodridge, Supai(?), and Moenkopi formations, including in the latter the De Chelly(?) sandstone lentil.

In the Moab area most of the terminology that has been applied, shown in Figure 11, is of fairly recent date. It has been discussed in some detail in a recent paper[6] and will be treated only briefly here. The Permian section at Moab itself is a duplicate of that in southwestern Colorado with the Hermosa, Rico, and Cutler formations, though overlain by the Lower Triassic Moenkopi formation. Near the junction of the Green and Colorado rivers the Hermosa and Rico are present, but the Cutler in large part passes laterally into the large sandstone called by Longwell and Paige[7] Coconino and here called the Cedar Mesa member. Part of it remains as red beds, the upper Cutler of this paper, considered by them to be lower Moenkopi. A relatively thin white sandstone at the very top has been called the De Chelly(?) lentil, but is here given the local name of White Rim sandstone, by which it is well known to many geologists, and is made the White Rim sandstone member of the Cutler. It is well shown in the White Rim, a marked bench between Green and Colorado rivers. The true Moenkopi was considered by Longwell and Paige to be only upper Moenkopi, and the beds beneath the Cedar Mesa sandstone, the Rico of the Moab section, were called Supai(?).

[1]H. E. Gregory, *op. cit.*, pp. 27, 32.

[2]Dorsey Hager, *op. cit.*, p. 137.

[3]N. H. Darton, "A Résumé of Arizona Geology," *Univ. of Arizona Bull. 119* (1925), pp. 85, 91, 110; Pls. 16, 17a, 18a, 25b, 26b, 61b-c, 62a-b, 63a-b; Figs. 30, 31.

[4]*Idem*, "A Reconnaissance of Parts of Northwestern New Mexico and Northern Arizona," *U. S. Geol. Survey Bull. 435* (1910), pp. 35, 43, Pl. 9.

[5]C. R. Longwell, H. D. Miser, R. C. Moore, Kirk Bryan, and Sidney Paige, "Rock Formations in the Colorado Plateau of Southeastern Utah and Northern Arizona," *U. S. Geol. Survey Prof. Paper 132* (1923), pp. 1-25.

[6]A. A. Baker, C. E. Dobbin, E. T. McKnight, and J. B. Reeside, Jr., "Notes on the Stratigraphy of the Moab Region, Utah," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), pp. 785-808.

[7]C. R. Longwell and others, *ibid.*, p. 8, Pl. 2.

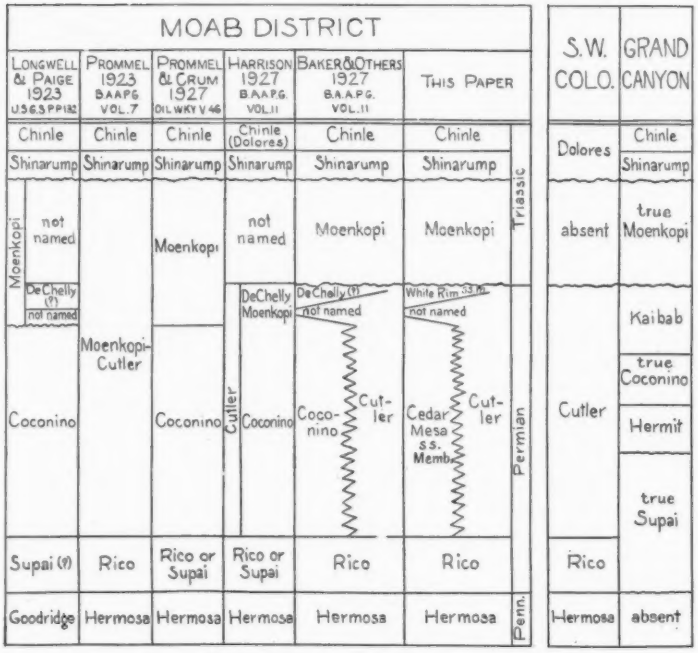

FIG. 11.—Nomenclature in the Moab district, Utah. That of southwestern Colorado and Grand Canyon region shown for comparison.

Prommel[1] in 1923 used the name "Moenkopi-Cutler" for the beds between the Rico and the Shinarump, and in 1927 he and Crum[2] used Moenkopi for the beds between the Coconino sandstone (of Longwell and Paige) of Cataract Canyon and the Shinarump conglomerate. They considered Rico and Supai(?) identical. In 1927 also Harrison[3] used the names Rico or Supai and Cutler, dividing Cutler into Coconino, Moenkopi, and De Chelly.

[1]H. W. C. Prommel, "Geology and Structure of Portions of Grand and San Juan Counties, Utah," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), pp. 384-99.

[2]H. W. C. Prommel and H. E. Crum, "Structural History of Parts of Southeastern Utah," *The Oil Weekly*, Vol. 46 (1927).

[3]T. S. Harrison, "Colorado-Utah Salt Domes," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11 (1927), p. 115.

The relations of the subdivisions of the Cutler formation north and south from Monument Valley are shown diagrammatically in Figure 12.

ORIGIN OF THE PERMIAN SEDIMENTS

No study has been made of the mineralogic composition and minute characters of the Permian rocks of the area dealt with in this paper, nor has more than casual attention been paid to the matter of sources and

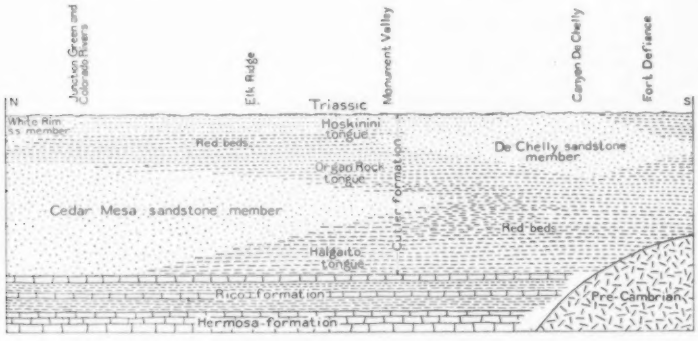

FIG. 12.—Diagram of relations of formations north and south from Monument Valley.

manner of origin of the sediments. Something may be inferred, however, from the distribution, relative thickness, gross lithology, and fossil content as to the derivation and manner of deposition of the formations.

There seems little doubt that the material of the Permian red beds came chiefly from the east, for they are in large part coarse arkoses in Colorado and eastern Utah, becoming finer grained and finally passing into non-red rocks westward. The lower red beds extend farthest westward, but even they eventually pass into non-red rocks. Very probably the pre-Cambrian of western Colorado was the chief source of the materials. In the eastern part of the area dealt with in this paper the red beds contain interbedded marine limestones in the lowest part (Rico formation), and the fauna preserved in them consists largely of pelecypods most closely related to those of the Permian of the Mississippi Valley. No similar fauna is reported in the central and western parts of the region, and the contemporaneous deposits there may have been entirely nonmarine. The overlying red beds (Cutler formation) contain little to suggest a marine origin, the types of bedding and the character

of the materials suggesting rather a fluviatile origin and probably rapid deposition. The presence of thick beds of gypsum at some localities, as at Comb Ridge north of San Juan River, and of layers containing casts of salt crystals, as at Hunter Point south of Fort Defiance, together with the incomplete decay of some of the minerals suggests aridity.

Fingering into the red beds from the northwest, in the case of the Cedar Mesa member of the Cutler, and from the southeast in the case of the De Chelly member, are the light-colored, much cross-bedded and rather thick-bedded sandstones of very different aspect. Certainly a considerable part of these sandstones is water-laid, though other parts appear to be wind-laid over wide areas, including the well known Canyon De Chelly. They represent the product of more mature weathering and sorting, for they are chiefly of quartz. Possibly also the immediate sources of the material were chiefly older sediments. If the greater thickness be assumed to lie toward the source of the materials the Cedar Mesa member came from the northwest. The dominant dip of the planes of the cross-bedding accords with this. On this assumption, and also judging from the direction in which it fingers out, the De Chelly member came from the southeast, though its maximum thickness, at Canyon De Chelly, appears more or less isolated and possibly its source is really the same as that of the other light-colored sands. The Coconino sandstone of the Grand Canyon region, very much like the Cedar Mesa and De Chelly sandstones and probably of like origin, thins northwestward and westward between the overlying Kaibab limestone and the underlying red beds, but at the same time the red beds (Hermit and Supai formations) acquire non-red members progressively until in southwestern Utah and eastern Nevada the red coloring is nearly lost and the interval between the Pennsylvanian and the Kaibab limestone is all thick, light-colored, cross-bedded sandstone. Schuchert,[1] on the basis of the dominant southerly or southeasterly dip of the planes of cross-bedding, postulated a northern or northwestern source for the Coconino in spite of its thinning in that direction. It seems to the writers highly probable that all of the light-colored sandstones came from the north or northwest.

The Kaibab limestone has its maximum thickness in the west, in southwestern Utah and eastern Nevada. It contains, however, several members of soft, gypsiferous shale, gypsum, and sandstone that indicate important interruptions in the deposition of the massive limestone more characteristic of the formation. Eastward and southeastward it thins,

[1]Charles Schuchert, "On the Carboniferous of the Grand Canyon of Arizona," *Amer. Jour. Sci.*, Ser. 4, Vol. 45 (1918), p. 349.

nearly at the rate at which the Coconino thickens, until only a remnant is left, this remnant being uniformly the highest Kaibab, long called the "Bellerophon limestone." In a sense the thick Kaibab of the west changes bed by bed into the thick Coconino of the east, and the Coconino in turn changes farther east into the red beds of the Cutler. No marine fauna comparable to that of the Kaibab in composition is known in southeastern Utah, southwestern Colorado, or northeastern Arizona, except that reported in a very thin limestone on Moonlight Creek by Darton. The writers did not succeed in rediscovering this locality, but it probably represents a brief eastward extension of the sea in early Kaibab time. The Chupadera formation of northwestern New Mexico, with its fauna of Kaibab aspect, must connect by some route south of the area here discussed with the Kaibab of the Grand Canyon region. The Kaibab fauna is said to be of Asiatic relationships and not closely related to any known farther east. Apparently the Kaibab sea came in from the west or southwest.

In brief, the Permian sediments of northern Arizona, southern Utah, southwestern Colorado, and northwestern New Mexico seem to present a picture somewhat as follows. A large area was receiving red sediments from the east, probably borne by rivers from granitic highlands, the climate more or less arid. Into the eastern part of this region there came a few incursions of an eastern sea, bringing with them the deposition of limestone. On the extreme western margin light-colored sands were brought in by streams. As time went on the light-colored sands came in from the whole northwestern margin, extending farther and farther out into the area and displacing the red sediments. At places the sands, including parts of the Coconino, Cedar Mesa, and De Chelly, were reworked by the wind. Then a western sea began to send its waters from the west or southwest and, as it advanced, the zone where the light-colored sands prevail advanced ahead of it, though in the extreme eastern part the red sediments continued to be deposited. Finally, and practically at its maximum, the sea was withdrawn and the area was subjected to the period of erosion represented by the unconformity at the base of the Moenkopi formation. What the length of this period may have been is indeterminable from the region itself and must eventually be gauged by other regions where the gap between the Permian and the Lower Triassic is more or less bridged.

SOME APPLICATIONS OF THE STRAIN ELLIPSOID[1]

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ABSTRACT

The strain ellipsoid is a solid or a three-dimensional conception, and its application should be made with that fact in mind. The angle-relationship between the axis of compression and the planes of no distortion is dependent upon the relative lengths of the three principal axes. Shear planes manifested as intersecting lines in the horizontal indicate that the greatest elongation was not upward but lateral. Parallel lines of shear in the horizontal suggest that the greatest elongation was upward. An application of the imaginary strain ellipsoid is made to an experimentally deformed mass as well as to regional structure.

INTRODUCTION

In his text book *Structural Geology* C. K. Leith[3] devotes about six pages to a description of the strain ellipsoid and its use in describing the relationship between stress and strain. He also gives a simple device for a two-dimensional illustration "of the ellipsoid through the plane of greatest and least axes of strain"—the well-known wire-netting model. He is careful to warn the student that

> the model, of course, shows only the cross-section of the ellipsoid through the plane of the greatest and least axes of strain. It does not show the position of the mean axis. Great care must be taken, in this as in other two-dimensional representations of deformation, to keep clearly in mind the relationship between the cross-section and the third dimension.

The present writer believes that many students have not taken heed of this warning; consequently, they have made misapplications of the strain *ellipsoid* by considering it merely as a strain *ellipse*.

The relationship of the hypothetical planes of no distortion or planes of shear, with respect to the three mutually perpendicular axes of any given strain ellipsoid, is absolutely definite (Fig. 1). The two planes of no distortion intersect each other along a line which includes the inter-

[1]Manuscript received by the editor, July 13, 1929.
The writer is indebted to R. T. Chamberlin, of the University of Chicago, for helpful criticisms.

[2]Imperial Oil, Ltd.

[3]C. K. Leith, *Structural Geology*. Revised Edition, pp. 21-27. Henry Holt and Company (1923).

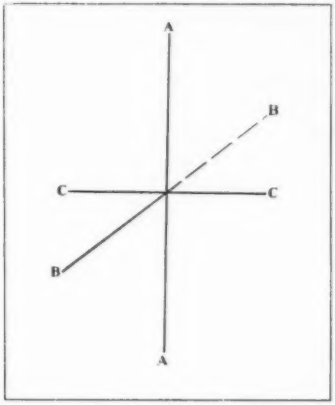

FIG. 1.—Illustrating the three principal axes of an ellipsoid. *A-A*, axis of greatest elongation; *C-C*, axis of compression; *B-B*, axis of intermediate elongation or compression. The planes of no distortion intersect along the *B-B* axis, and represent the only two circular sections through the ellipsoid.

mediate axis (*B-B*), and these planes of no distortion represent circular sections through the ellipsoid whose diameters equal the *length of the intermediate axis* (*B-B*). This must always be the case if there are three unequal axes. In this discussion the longest axis will be referred to as the *A-A* axis, the intermediate the *B-B*, and the shortest the *C-C* axis[1] (Fig. 1).

A *prolate spheroid*, in which the *A-A* and *B-B* axes are equal in length, has only one plane of no distortion which includes within it these two longer equal axes. Likewise, an *oblate spheroid*, in which the *B-B* and *C-C* axes are equal, can have only one plane of no distortion which includes within it the two shorter equal axes.

[1]A clear understanding of the properties of an ellipsoid is necessary before it can be applied to structural problems. An excellent means of becoming thoroughly acquainted with the properties of an ellipsoid is the drawing of ellipses of various dimensions and constructing models which include the principal axes and the planes of no distortion in their proper relative positions. Mathematical formulae, giving the volume of a sphere and an ellipsoid as well as the eccentricity and ellipticity of an ellipse, should also be understood. Due to the writer's reluctance to use mathematical formulae in the field of structural geology none is incorporated in the text of this paper. The reader can find such information in the elementary text books on this subject. The major part of this paper consists merely of a graphic presentation of these formulae. It is obvious that in considering a given sphere deformed into an imaginary ellipsoid, the two must be of equal volume; consequently, the problem becomes quantitative. Such applications are, in the writer's opinion, not practical in structural geology at present, since they would require a knowledge of the relative, as well as the absolute magnitude of the forces involved.

A condition in which the *A-A* and *B-B* axes are equal (a *prolate spheroid*) could arise from compressive forces parallel with the *C-C* axis with an equal relief of stresses along the two equal axes, *A-A* and *B-B*. Expressed in another way, it would amount to a lateral elongation or relief equal to the upward relief of stresses. In this case, the one plane of no distortion or shear lies perpendicular to the *C-C* axis, if non-rotational compression caused the deformation.

These two cases seem rather improbable conditions in nature, though not impossible. The three principal axes of strain are ordinarily unequal. In non-rotational compression the shortest axis (*C-C*) is also termed the axis of compression, while the longest axis (*A-A*) is the axis of elongation, and the intermediate axis (*B-B*) is either that of lesser elongation or lesser compression (Fig. 1).

REGIONAL APPLICATIONS

If it is assumed that the Rocky Mountains of the western United States and Canada were caused by non-rotational compression, it seems most reasonable to assume a regional application of the strain ellipsoid to be somewhat as follows. The axis of compression (*C-C*) should strike northeasterly and southwesterly, which is at right angles to the trend of the range. The intermediate axis (*B-B*) should strike northwesterly and southeasterly, or parallel with the range, and the axis of elongation should stand perpendicular to the surface. (See upper part of Figure 2.) If such is the case, the planes of no distortion or shear, which intersect along the intermediate axis (*B-B*), would strike northwesterly-southeasterly. This is evidenced by the trend of the folds and faults of this mountain chain. Irrespective of whether the *B-B* axis is one of lesser compression than along *C-C*, or lesser elongation than along *A-A*, such a position of the strain ellipsoid appears to be the correct application. This application of the strain ellipsoid to a mountain range has already been made by Chamberlin,[1] who used it in an analysis of the Appalachian Mountain structures. In cross section the planes of no distortion would appear as intersecting shear planes, as presented in the wire netting model of the strain *ellipse*.

The object of the preceding discussion is merely to point out that in applying a strain *ellipse* to a mountain chain, caused by surficial compressive forces, one must use in the *horizontal plane* that plane of the *ellipsoid* which includes within it the *B-B* (intermediate) and the *C-C*

[1] R. T. Chamberlin, "The Strain Ellipsoid and Appalachian Structures," *Jour. Geol.*, Vol. 36, No. 1 (1928).

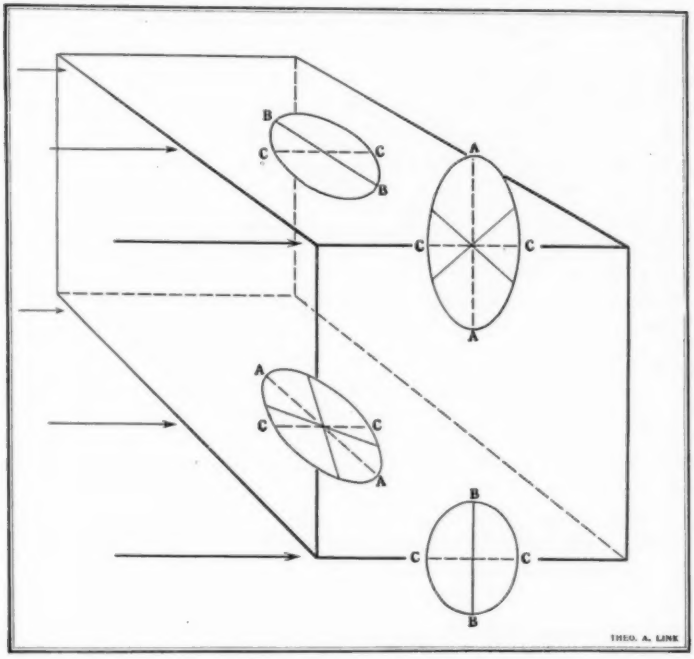

FIG. 2.—Block diagram illustrating regional applications of the strain ellipsoid near the surface and at depth. Compressive forces operative as indicated by the arrows. At or near the surface the greatest relief of stresses is *upward;* therefore, the axis of greatest elongation (*A-A*) stands perpendicular. The intermediate (*B-B*) axis lies in the horizontal, and coincident with it is the intersection of the planes of no distortion, so that these appear, in the horizontal, normal to the axis of compression, but in cross section they appear as intersecting lines.

At depth the *A-A* axis of greatest elongation lies in the horizontal, so that the planes of no distortion stand perpendicular in cross section and appear as intersecting lines in the horizontal. (The ellipses in the horizontal are distorted due to the perspective.)

(shortest) axes, and not the *A-A* axis of greatest elongation. The latter, (the *A-A* axis) together with the *C-C* axis, lies, in this case, in the plane of cross section.

The statements just made are, of course, not applicable to all areas. There are, without any doubt, regions where intersecting planes of no distortion or shear have been observed in the horizontal. (See Figure 2, lower part.) In applying the strain ellipsoid to such a condition it is obvious that in the horizontal plane lie the axis of greatest elongation

(*A-A*) and the axis of compression (*C-C*), and that the intermediate axis (*B-B*) stands vertical or perpendicular to the surface. This necessarily implies that the greatest *relief* of stresses was *not upward*, but *horizontally* or laterally along the *A-A* axis, while the intermediate relief of stresses was vertical. Consequently, the *strain ellipse*, applied in cross section, would show lines of no distortion or shear standing vertical and parallel with one another. Becker[1] called attention to this fact many years ago, but some current applications of the strain ellipsoid lead one to believe that the subject has not been sufficiently analyzed.

Conditions giving rise to systems of intersecting lines of undeniable shear in the horizontal plane seem unlikely to occur near the surface. When tangential compressive forces, such as apparently gave rise to most of the folded mountain systems, are operative, the greatest relief should be upward, and therefore the *A-A* axis must stand perpendicular to the surface, as was explained by Chamberlin in connection with the Appalachian Mountains. At depth, approaching the zone of flowage, one could visualize the conception that the greatest relief to tangential compressive forces may be lateral, because upward relief of stresses might be more difficult on account of the overlying weight of rock. Here, then, one would expect to find planes of no distortion or shear intersecting in the horizontal which appear as perpendicular and parallel lines in cross section. (See lower part of Figure 2.) If this reasoning is correct, it should be possible to determine whether a given area was deformed at great depths or near the surface. In doing so, the observer must be able to distinguish planes of shear from joint planes which have a different origin.

The possibility of conditions in which the three mutually perpendicular axes of the imaginary strain ellipsoid stand neither perpendicular nor horizontal to the surface, must also be regarded as an important consideration in its application and the possibility that such may have been the fact for the Appalachian and Rocky mountains is worthy of consideration. Such possibilities may exist irrespective of whether the stresses were rotational or non-rotational.

STRAIN ELLIPSOID AN IMAGINARY CONVENTIONAL FORM

The strain ellipsoid is an imaginary and conventional form, as explained clearly by Leith.[2]

[1] G. F. Becker, "Finite Homogeneous Strain, Flow and Rupture of Rocks," *Bull. Geol. Soc. Amer.*, Vol. 4 (1893), p. 50.

[2] It was suggested that the "stretched pebbles" of Appalachian conglomerates be considered as an example. This would necessitate the assumption that all these pebbles were originally *perfect* spheres and that they now answer the mathematical description of *perfect* ellipsoids.

It is sometimes convenient to describe "strain" and the relationships between "strain" and "stress" in terms of a conventional form known as the *strain ellipsoid*. Any imaginable sphere of a solid body, when deformed in a single homogeneous strain, becomes a strain ellipsoid.

The writer knows of no example of a hand specimen of a strain ellipsoid found or observed in the bed rock of the earth, nor an example of one produced in the laboratory. Farther on Leith[1] states:

Where we know the directions of elongation and shortening in a rock, we can conceive of these in terms of the strain ellipsoid, and thus visualize the deformation which the rock has undergone.

The application of the strain ellipsoid to any given structural problem proves or solves nothing in particular. It is merely an aid to visualizing structural conditions. In a recent article Stark[2] applied the strain ellipsoid and after doing so claimed that

Hartmann's Law, indicating that for brittle substances the direction of greatest compressional stress bisects the acute angles of the joints, does not seem applicable here.

Irrespective of whether Hartmann's law is applicable or not in that area, the application of the strain ellipsoid neither proves nor disproves it. By applying the strain ellipsoid as he did, Stark merely indicated his interpretation of structure. Farther on Stark states:

The orientation of the *ellipsoid* would, in either case, lie with its longest axis in general parallel to the almost vertical dip of the bedding in the sediments, and its least axis at right angles to the trend of the folds. (The italics are the writer's.)

Nevertheless, on his map he shows intersecting shear lines in the *horizontal* plane, which is an impossibility if "the longest axis lies parallel to the almost vertical dip of the bedding." He used the term "*ellipsoid*" but made no mention of the intermediate axis. Therefore, by examining his map, one is led to believe that the *longest* axis lies in the *horizontal*, and the *intermediate* axis stands *vertical*. By using the *ellipse*, as he did on his map, with the longest (*A-A*) and shortest (*C-C*) axes lying in the horizontal, one must necessarily conclude that the greatest elongation was regarded as lateral and the lesser elongation was upward and vertical. To be brief, the text of his paper does not correspond with the map as far as the application of the strain ellipsoid is concerned.

[1]C. K. Leith, *Structural Geology*. Revised Edition, Henry Holt and Company (New York, 1923), pp. 21-22.

[2]J. T. Stark, "The Primary Structure of the Kekequabic Granite," *Jour. Geol.*, Vol. 35, No. 8 (1927), pp. 731-32.

On a photograph of an experimentally produced structure, Brown[1] drew an ellipse and explained:

"The white ellipse represents the strain ellipsoid," but here again no mention was made as to what particular cross section of the strain ellipsoid this ellipse was intended to represent. Was it the *A-A* and *C-C* axes, or the *B-B* and *C-C* axes represented in the horizontal? It makes a very great difference which cross section of the ellipsoid it is supposed to represent. On the opposite page of the same article Brown stated:

> The long axes of the folds and strike of the thrust faults were parallel to the long axis of the strain ellipsoid, while the strike of the normal faults was parallel to the short axis of the strain ellipsoid.

After reading the preceding and following part of the text, the writer must admit his failure to see any simplification of the problem by an application of the strain ellipsoid. There is no imaginable strain ellipsoid in which the planes of no distortion include, or lie parallel with, all three axes. The planes of no distortion must always intersect along the intermediate (*B-B*) axis and lie at varying angles with respect to the longest and shortest axis. The two exceptions to this rule (the oblate and prolate spheroid) have already been mentioned as occurring when two of the axes are equal, and in both these types of spheroid there is only one plane of no distortion (page 1450).

The strain *ellipse* was also applied by Foley[2] in the horizontal plane to explain the origin of the *en échelon* faults and related structures in north-central Oklahoma. On the map accompanying his article he drew a figure representing the strain ellipse; the line *C-C* was termed, "the axis of compression," and *T-T*, "the axis of elongation." No mention was made of the intermediate axis; therefore, one must assume that the applied ellipse represents the cross section of the strain ellipsoid in which lie the shortest and longest axes. This is confirmed by further reading of the article where it is pointed out that the N. 40° W. trending tension fractures and the NE.-SW. oriented folds are regarded as manifestations of the planes of no distortion. If such is the fact, then the intermediate axis *B-B* stands vertical or perpendicular to the surface and the greatest elongation was laterally NE.-SW., while the lesser elongation was upward; therefore, the structures of Osage and Creek counties were, according to Foley's strain ellipsoid application, produced at considerable depth

[1]R. W. Brown, "Experiments Relating to the Results of Horizontal Faulting," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 7 (July, 1928), Fig. 1, p. 719.

[2]L. L. Foley, "The Origin of the Faults in Creek and Osage Counties, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 3 (March, 1926), pp. 293-303.

where upward relief was less than the lateral relief of stresses (Fig. 2). In this particular situation it seems extremely doubtful.

EXPERIMENTAL EVIDENCE

Whether or not it would be possible to deform a perfect sphere of homogeneous material by compression into a true strain ellipsoid with the planes of no distortion and the three axes in their proper place remains to be demonstrated. Theoretically it should be possible. The writer deformed spheres of plaster of Paris by compression between two push-blocks, as illustrated in Figure 3, but no true strain ellipsoid resulted, nor did the planes of shear develop so that the direction of greatest compressional stress bisected the obtuse angles of the shear planes. These results, as well as practically all experiments in which cubes of homogeneous materials are subjected to compression, seem at variance with the current conception of the strain ellipsoid.

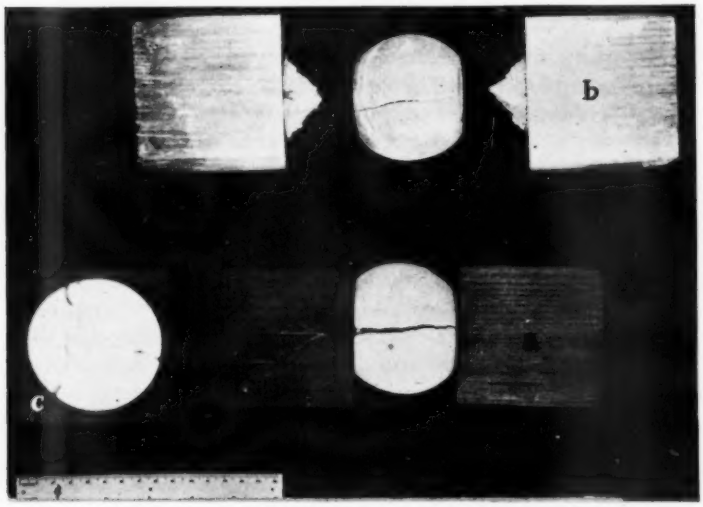

FIG. 3.—Sphere of plaster of Paris deformed by non-rotational compression. (a) Nature of compressive forces applied from left. Notice that the deformed sphere is not an ellipsoid. (b) Cones of shear with planes close to 45° with respect to axis of compression. (c) End view of deformed sphere showing three tension fissures developed at regular intervals.

In 1926-27 a series of more than fifty experiments was performed by the writer[1] in the structural geology laboratory at the University of Chicago. Various types of pressure boxes were employed and the manner of pressure application also varied. In only one of these experiments was an application of the strain *ellipse* in the horizontal plane, including the axis of elongation (*A-A*) and the axis of compression (*C-C*), feasible. In all other tangential compression experiments the strain *ellipse* in the horizontal plane included the intermediate (*B-B*) axis and the (*C-C*) axis of compression. That such must be the fact in an ordinary pressure box, commonly used by experimenters, is quite obvious, since confining walls allow no horizontal spread, so that nearly all relief of stresses must be *upward*. Although the writer applied compressive forces and built some of the apparatus in such a manner as to allow a lateral spread or relief of stresses, in only one experiment was it sufficient to cause a development of shear planes appearing as intersecting lines in the horizontal.[2]

DEFORMATION OF A CYLINDER CONTAINING ARTIFICIAL SEDIMENTS

A cylinder made of tin was filled with artificially prepared sediments as shown in Table I.

TABLE I

EXPERIMENT NO. 29 (APPARATUS "D")

Record of Sediments				
Stratum	*Kind of Material and Proportions in Kilograms*		*Weight in Kilograms*	*Thickness in Centimeters*
Overburden	None		....	....
Clay No. 2	Plastic blue mud (clay)	2.75		
	Mixed with cement	0.40	3.15	4.60
Petrolatum No. 2	Petrolatum (grease)	0.23	0.23	0.40
Clay No. 1	Plastic blue mud (clay)	2.75		
	Mixed with cement	0.40	3.15	3.50
Petrolatum No. 1	Petrolatum (grease)	0.23	0.23	0.50
Sand No. 1	Sand	5.20		
	Mixed with cement	1.00		
	and water	2.90	9.10	6.50
	Total		15.86	15.50

[1]Theodore A. Link, "Three-Dimensional Experiments in Earth Deformation," *Univ. of Chicago Abstracts and Theses*, Science Series, Vol. 5 (1926-27), pp. 277-81.

[2]*Idem*, "The Origin and Significance of 'Epi-Anticlinal' Faults as Revealed by Experiments," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 8 (August, 1927), pp. 853-66.

Notice that the total thickness of the plastic material was 9.00 centimeters, and that of the cemented sand 6.50 centimeters.

After deposition of the uppermost layer the cylinder was photographed from above, as shown in Figure 4. Before the plastic clay layers had an opportunity to solidify, pressure was applied against one side by means of a jack-screw and a board, while the opposite side was placed against a resisting wall, as shown in Figure 5. Incipient shear planes were already noticeable at this stage. Further compression developed larger and more numerous shear planes. The sideward extension, or lateral spread of the mass, was evidently greater than the vertical or upward relief, as evidenced by the shear planes manifested as intersecting lines in the horizontal strikingly shown in Figure 6. Tension was also operative, as indicated by the gaping of these planes. Further compression accentuated the already developed features, as shown in the final stage in Figure 7. The amount and nature of deformation is summarized in Table II.

TABLE II

	Centimeters	
Original diameter of cylinder	26.0	
Compressed diameter of cylinder	11.8	(*C-C* axis of strain ellipsoid)
Amount of compression	14.2	
Elongated diameter of cylinder	35.0	(*A-A* axis of strain ellipsoid)
Amount of elongation	9.0	
Thickness of sediments before application of pressure	15.5	
Thickness of sediments after application of pressure (at center of uplift only)	23.1	(*B-B* axis of strain ellipsoid)
Total average uplift in center	7.6	

The figures in Table II show clearly that the vertical rise of the deformed mass was less than the lateral spread; consequently, an application of the strain ellipsoid, in this particular case, would require that the longest axis *A-A* (greatest elongation) and the shortest axis *C-C* (compression) should lie in the horizontal plane, and the intermediate axis *B-B* (in this case intermediate elongation) must stand vertically, as shown in Figures 7 and 8. That this was to be expected is evident from the nature of the pressure application, the nature of the materials used as sediments, and the absence of any appreciable resistance to their lateral spread. In nature deformation of this kind should be expected at depths below the surface at which a considerable overburden prevents an unhindered vertical rise and where plastic or semi-plastic conditions of the rocks should encourage a lateral spread or relief of compressive forces. (See lower part of Figure 2.)

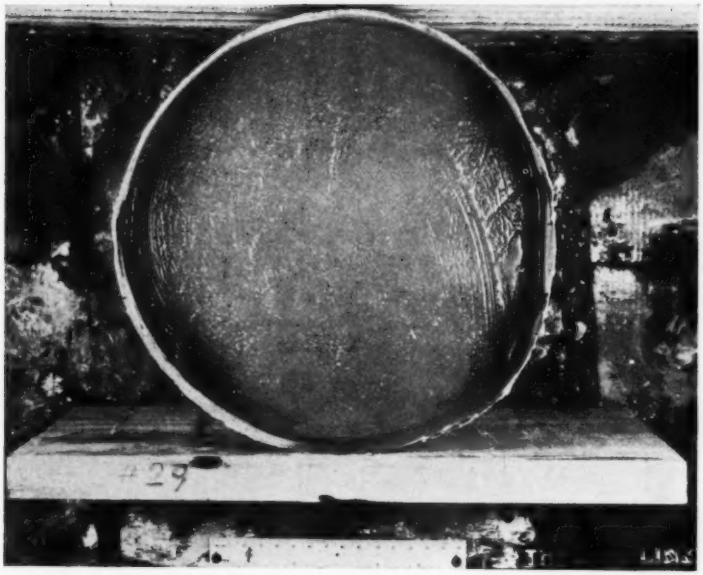

FIG. 4.—Top view of cylinder to be deformed by compression from lower side. Sediments deposited in cylinder given in Table I. Scale represents 15 centimeters.

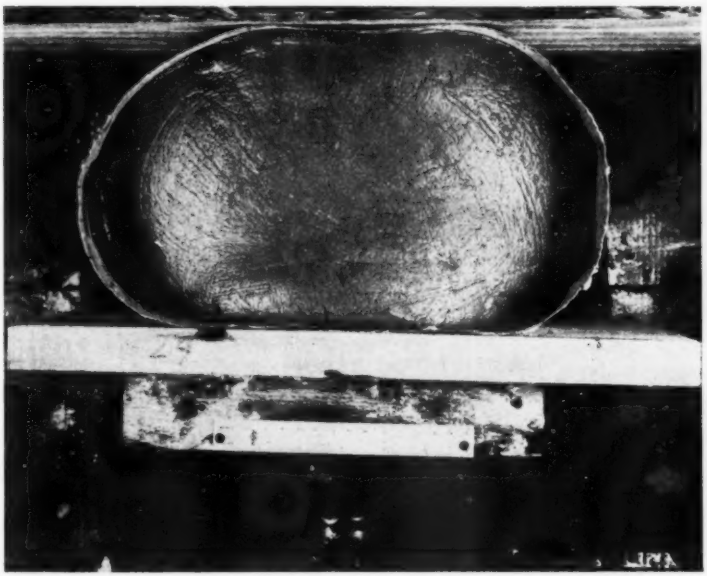

FIG. 5.—Top view of same cylinder as in Figure 4, after slight compression. Notice the incipient shear planes.

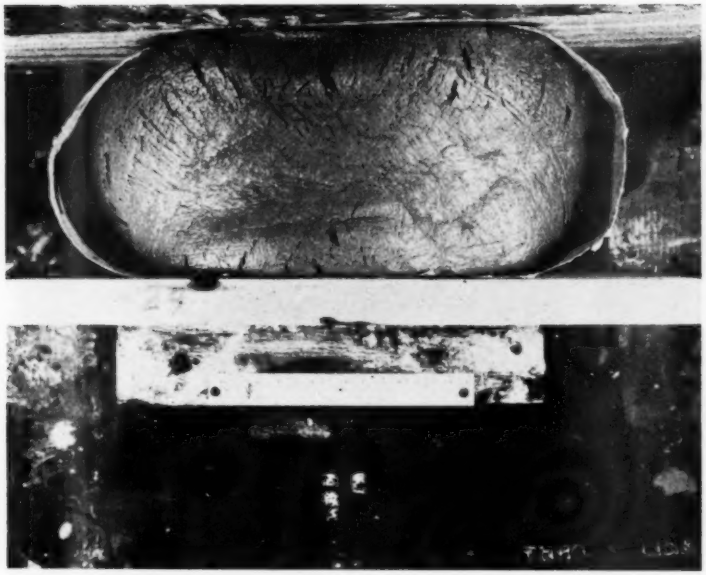

FIG. 6.—Top view of same cylinder as in Figures 4 and 5, after additional compression. Intersecting shear planes are conspicuously developed and show gaping due to tension.

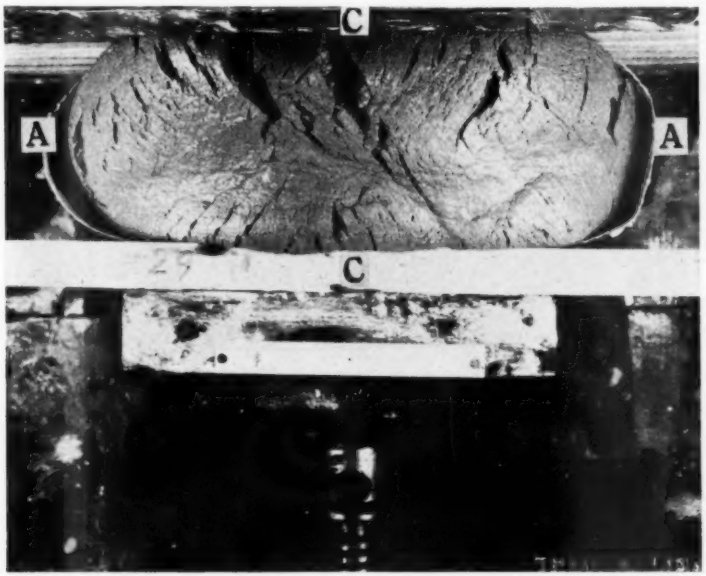

FIG. 7.—Final stage of deformed cylinder. The amount of compression, elongation, and vertical rise is given in Table II. The intersecting shear planes are clearly shown. *A-A* represents the axis of greatest elongation and *C-C*, the axis of compression of the imaginary strain ellipsoid.

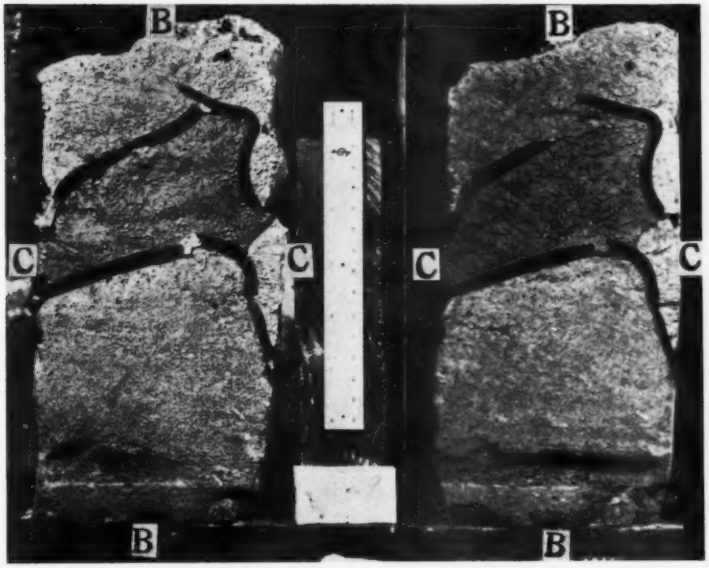

FIG. 8.—Cross section cut through *C-C* axis of deformed cylinder illustrated in Figure 7. Notice the *apparent* thrust fault in left figure which is same as normal fault in right figure. The two figures represent the same cross section on opposite sides of saw blade used to cut the section. *B-B* represents the intermediate axis and *C-C* the axis of compression of an imaginary strain ellipsoid. Scale equals 15 centimeters.

A cross section cut through this deformed mass is illustrated in Figure 8. On the basis of the strain ellipsoid one would expect to find lines representing essentially vertical shear planes in this cross section, but *apparently* none is to be observed. This is, however, only *apparent*. The displacement in the upper dark grease layer *appears* on the left in Figure 8 to be along an inclined plane (a thrust fault). In reality, however, it is due to a horizontal displacement along a true vertical shear plane, as evidenced by the same shear plane on the right in Figure 8.

POSITION OF PLANES OF NO DISTORTION AND NATURE OF MATERIALS

At the beginning of this article it was stated that if the *C-C* and *B-B* axes are equal (an oblate spheroid) there can be only one plane of no distortion including within it these two axes of equal compression. Furthermore, if the *A-A* and *B-B* axes are equal (a *prolate spheroid*) there is also only one plane of no distortion which includes the two axes of

equal elongation. Further consideration of the problem should lead to an understanding as to where the planes of no distortion *must* lie in an *ellipsoid* when no two of the axes are equal. It is obvious that if the intermediate *B-B* axis is only slightly longer than the *C-C* axis of compression, but considerably shorter than the *A-A* axis of greatest elongation, the planes of no distortion should lie so that the *C-C* axis will bisect a small *acute* angle made by these planes, as shown in Figure 9. Likewise, if the intermediate *B-B* axis is only slightly shorter than the *A-A* axis of greatest elongation, but considerably longer than the *C-C* axis of compression, the planes of no distortion should lie so that the *C-C* axis bisects a large *obtuse* angle made by the planes of no distortion, as shown in Figure 9. In fact, one can figure mathematically or graphically *exactly* where the planes of no distortion must lie with respect to the axis of compression if the lengths of the three axes are known. This should make it clear that an ellipsoid can have the planes of no distortion in a position in which the angle made by their intersection is a right angle only when a definite ratio exists between the three principal axes. The same is true for any other given angle. This may be stated much more simply as follows: *The angle of intersection of the planes of no distortion is dependent upon the relative lengths of the three axes.* Consequently, it should be possible to produce, by simple non-rotational compression, an imaginary ellipsoid in which the axis of compression bisects either an acute or an obtuse angle of the intersecting planes of no distortion. This being true, it is necessary to discard the current conception[1] that

> In non-rotational strain the planes of maximum shear are theoretically 45° to the direction of greatest pressure, which is also the axis of most shortening or least axis of strain.

The fact that this statement is not entirely true is explained farther on by Leith as follows: "Actually, because of internal friction, they are usually at smaller angles to this direction." This reference to friction does not seem adequate and further inquiry into this matter is desirable. An examination of numerous experiments described by previous investgators, as well as of those performed by the writer, shows most conclusively that in most cases the axis of compression bisects the acute angle of the intersecting planes of shear (Figs. 10 and 11). The reason for this is not far to seek, as already pointed out. In an ordinary pressure box the greatest elongation is *upward*, while the confining sides prevent any appreciable lateral elongation. The difference in length between the *A-A*

[1] C. K. Leith, *op. cit.*, p. 20.

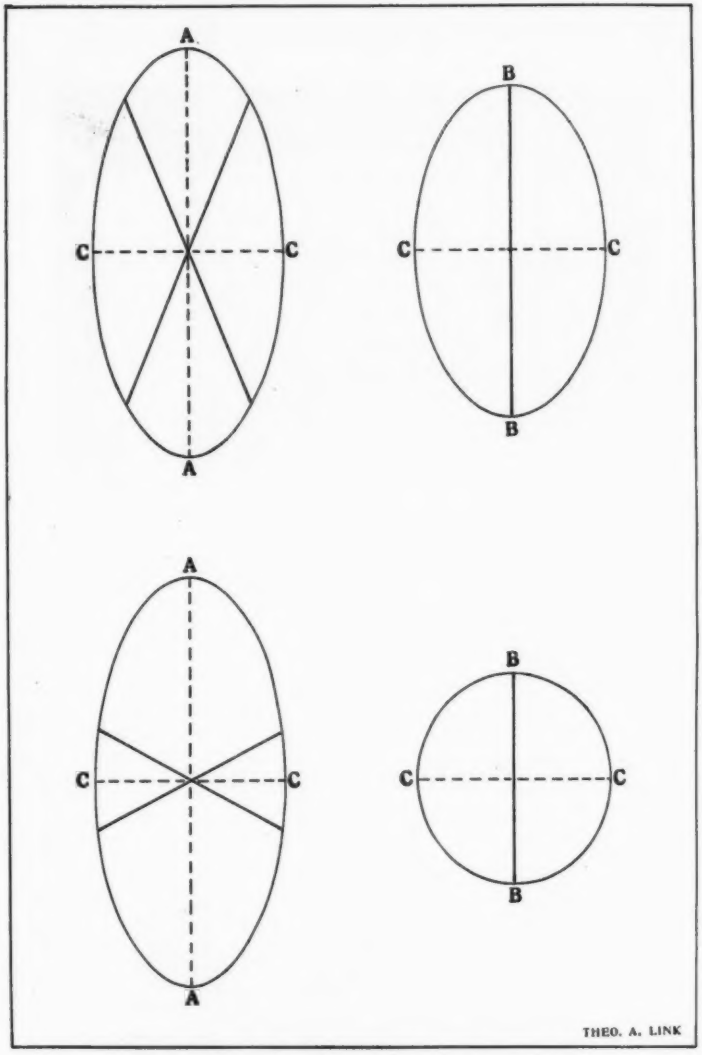

FIG. 9.—Illustrating how the position of the planes of no distortion in a strain ellipsoid are dependent upon the relative lengths of the three principal axes. *A-A* represents the axis of elongation. As the *B-B* axis approaches the value of *C-C*, the axis of compression bisects an acute angle of the planes of no distortion; as the *B-B* axis approaches the *A-A* axis in length, the axis of compression bisects an obtuse angle. This must be true, since the planes of no distortion intersect along the intermediate *B-B* axis and represent circles whose diameter equals the length of the intermediate axis. The axes are indicated by dotted lines, and the planes of no distortion by full lines. As these planes include the *B-B* axis, it is shown by a full line.

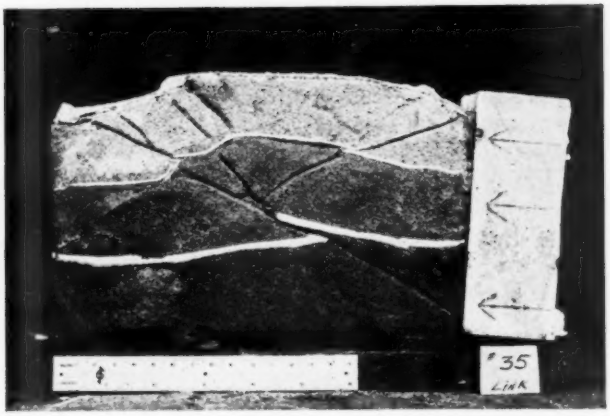

FIG. 10.—Non-rotational compressive forces giving rise to shear planes developed at an angle less than 45° to the axis of compression. Compressive forces applied from right, as indicated by the arrows.

and *B-B* axes is considerable, but the difference between the *B-B* and *C-C* axes is relatively small. In consequence, one would expect the planes of no distortion to lie close to the *C-C* axis of compression and more distant from the *A-A* axis of elongation. The result is, therefore, a bisecting of the acute angle of the planes of shear by the axis of compression. One might, on first thought, conclude that prolonged compression of rigid material should cause the *C-C* axis to become much shorter than the intermediate *B-B* axis, and that extreme compression should give rise to shear planes inclined at high angles so that the axis of compression

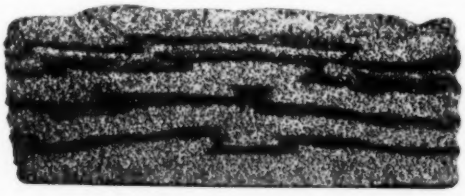

FIG. 11.—Non-rotational compressive forces applied from opposing sides, giving rise to intersecting shear planes developed at an angle considerably less than 45° to the axis of compression. (Illustration taken from Chamberlin's Figure 5, page 763, "The Wedge Theory of Diastrophism," *Jour. Geol.*, Vol. 33 (1925), No. 8).

intersects the obtuse angle. This, however, is not always the fact because another factor must be considered, namely, the *nature of the material.*

Experiments have shown that plastic material will not fracture until it has undergone considerable change in shape by compression, while rigid material ordinarily fractures after very little compression. Hartmann concluded that in *rigid* material the axis of compression bisects the *acute* angle of the planes of shear. This seems reasonable when one remembers that the fracturing of brittle materials takes place before there has been much change in shape—or when the intermediate axis is not much greater than the axis of compression. On the other hand, plastic material has to undergo considerable change in shape, so that the axis of compression is relatively much shorter than the intermediate axis *before* shearing takes place. Consequently, it is reasonable to conclude that in *plastic* material the axis of compression will bisect the *obtuse* angle of the planes of shear.

The foregoing analysis points decidedly toward a harmonous agreement between Hartmann's Law and a correct conception of the strain ellipsoid. It shows that an imaginary strain ellipsoid can be produced by non-rotational compression in which the *C-C* axis of compression may bisect an angle as low as 1° or as high as 180°. Furthermore, it raises serious question regarding the current conception that when the axis of compression bisects a high obtuse angle the stresses which caused the strain were rotational. Regarding this problem the writer hopes to give additional discussions in a later article.

CONCLUSIONS

In applying the strain ellipsoid to structural problems, students are reminded that it is a three-dimensional conception which should be kept clearly in mind. Furthermore, its application is a means whereby the student commits himself regarding his conception of the nature of the material deformed as well as the resulting strain and the stresses which caused it.

The use of the strain *ellipse* is to be discouraged unless definite mention is made as to what cross section of the strain *ellipsoid* it is intended to represent.

The angle at which the planes of no distortion will develop in a given mass is dependent upon the nature of the material and the relative amount of relief along the axes of elongation. The *absolute* amount of compression is not the controlling factor. Brittle and rigid material will develop relatively low planes of shear with very slight compressive forces and

will keep on developing them with the same definite angle relationship after prolonged application. Plastic material will not shear until prolonged application of compression, but after shearing has once commenced it will also be with the same definite angle relationship peculiar to the material in question, as demonstrated by Hartmann and so well understood in engineering practice. In rigid material the axis of compression normally bisects an acute angle of the planes of shear, while in plastic material an obtuse angle is bisected by the axis of compression.

Intersecting shear planes in the *horizontal* suggest *deep-seated compressive* forces, and intersecting shear planes in *cross section* indicate *surficial tangential compression.*

Finally, the application of the strain ellipsoid is to be regarded only as a convenient means whereby a given structural condition is made understandable. Its application *proves* nothing, but merely indicates a structural *interpretation.*

ACTION OF ORGANIC ACIDS UPON LIMESTONE[1]

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Tulsa, Oklahoma, and Urbana, Illinois

ABSTRACT

An attempt is made to estimate the effect on limestone of organic acids, developed as a result of bacterial decomposition of plants. Experimental evidence shows that, under favorable conditions, these acids may be the most effective solvents of limestone that exist in nature. They are particularly active in the development of porosity.

It has long been known that humus acids are factors in the chemical weathering of rocks, but little work has been done in determining the amount and kinds of acid which are available for this kind of weathering. M. M. Leighton[3] demonstrated that aërated distilled water had a greater solvent action on calcite after it had been filtered through peat than it had in the absence of organic matter. Soils high in organic material become acid to such an extent that certain crops can not grow, and it is known that if the waters from bogs and acid soils pass through calcareous sediments, solution will take place.

In forested regions the large amount of humus which accumulates on the tops of hills, on slopes, even though steep, and in valleys, is capable of producing a plentiful supply of organic acid by bacterial decomposition. These acids, when carried into the limestone below by downward percolating meteoric waters, will have the same effect as carbonic acid in developing cavernous and porous conditions in limestone.

ORGANIC ACIDS

There are in nature two groups of organic acids which may act as solvents of limestone. The first group is composed of acids which are

[1]Manuscript received by the editor, July 30, 1929.
This paper contains preliminary results obtained in an investigation of limestones and dolomites as reservoir rocks, listed as Project No. 23 of the American Petroleum Institute Research. Financial assistance in this work was received from a research fund donated by the Universal Oil Products Company to the American Petroleum Institute. This fund is being administered by the Institute with the coöperation of the Central Petroleum Committee of the National Research Council.

[2]American Petroleum Institute Research Assistants. Introduced by W. V. Howard.

[3]Personal communication.

produced by the plant during its growth and which are leached out after the plant dies. In the second group are acids produced by the bacterial decomposition of such plant materials as cellulose, hemicelluloses, pectin, and gums.

Thatcher[1] considers that in the first group, formic acid is probably one of the most plentiful and the most widely distributed of all of the free plant acids, that acetic, propionic and butyric acids are also found in many plants and are characteristic of certain species, and that oxalic acid is found in large proportions in some plants and in small amounts in nearly all. Fumaric acid, according to Holleman,[2] is somewhat widely distributed in the vegetable kingdom. Succinic[3] and malic acids are found in many fruits and vegetables, and tartaric acid only in fruits. Citrous fruits contain large amounts of citric acid,[4] while the seeds of the common leguminous vegetables also contain small amounts. Tannic acid,[5] which is produced commercially from oak bark, is widely distributed throughout the vegetable kingdom.

We do not know the quantities of these acids that are produced every year, or what percentage of these goes into the ground water, but, considering the vegetation which is, and was in past ages, present on the earth, we can reasonably believe that the quantity of organic acids formed annually amounts to many tons per square mile. Although these acids are not stable and would be oxidized within a few days under the influence of the atmosphere, it is highly probable that they do remain stable long enough to permit the solution of a considerable amount of limestone.

In the second group of acids, namely, those which are the product of bacterial decomposition, acetic and butyric acids seem to predominate, there being also smaller quantities of lactic and valeric acids. In retting liquors Kayser and Delavel[6] identified formic, acetic, butyric, succinic, and lactic acids, and in addition Stormer[7] identified valeric acid in the decomposition products of his anaerobic retting. That these acids are found in nature to a greater or less extent is shown by the fact that the

[1]R. W. Thatcher, *Chemistry of Plant Life* (1921), p. 126.

[2]A. F. Holleman, *Textbook of Organic Chemistry* (1920), p. 211.

[3]R. W. Thatcher, *ibid.*, p. 127.

[4]*Ibid.*

[5]A. F. Holleman, *ibid.*, p. 494.

[6]Cited by A. C. Thayson and H. J. Bunker, *Microbiology of Cellulose, Hemicelluloses, Pectin, and Gums* (1927), p. 177.

[7]*Ibid.*, p. 161.

waters of Nile River have been used for the retting of flax since the time of the Egyptians.[1] Omelianski[2] found that fermentation of 2.0815 grams of cellulose by *Bac. mellanigenes* produced the following:

	Grams
Fatty acids	1.0223
Carbon dioxide	0.8678
Methane	0.1372

and *Bac. fossicularum* on 3.4743 grams of cellulose produced:

	Grams
Fatty acids	2.2402
Carbon dioxide	0.9722
Hydrogen	0.0138

Khouvine, working with *Bac. cellulose dissolvens* on 1.102 grams of cellulose, obtained:

	Grams
Acetic acid	0.275
(?)n-Butyric acid	0.033
Ethyl alcohol	0.082
Carbon dioxide	0.1827
Hydrogen	0.0085
Pigment	0.0135

Ramann, Remeli, Shellhorn, and Krause,[3] in studying the relative importance of fungi and bacteria in the decomposition of shallow layers of vegetable matter, found that on taking the acidity of the decaying matter as zero, the mould was 0.65 *N*-0.98 *N*, the soil and mould mixture 0.251 *N*, and that of the surface soil, 0.007 *N*.

INSTABILITY OF ORGANIC ACIDS

All organic acids are readily oxidized under the conditions which exist on the surface of the earth, and are also unstable under those which exist below its surface. Very small amounts of organic acids are found in amber and lignite, and, according to Julian,[4] they are imprisoned in ferric hydrate and manganese oxide, but these amounts are negligible in comparison with the large quantities produced in nature. Ordinarily we do not think of calcium acetate as unstable, or vinegar as being readily oxidized, but when these substances are exposed to the action of ground

[1] Cited by A. C. Thayson and H. J. Bunker, *Microbiology of Cellulose, Hemicelluloses, Pectin, and Gums* (1927), p. 164.

[2] *Ibid.*, p. 55.

[3] *Ibid.*, p. 207.

[4] *Proc. Amer. Assoc. Adv.. Sci.* (1879), p. 330.

water and of the rocks with which they are in contact, the calcium acetate is converted to carbonate and the acetic acid is broken down to CO_2 and water. Probably it is because of the absence of the salts of organic acids in nature that, as Julian has said, their geologic work has been underrated or attributed to an excessive extent to carbon dioxide.

ORGANIC ACIDS IN GROUND WATERS

The use of the term "organic matter" in the analyses of mineral waters may, as suggested by Julian,[1] refer to a group of organic acids which are not determined in the ordinary water examination. He gives many analyses of waters showing organic acids and the salts of organic acids, which are present in small amounts and which may penetrate the rocks to considerable depths. The following analyses given by him[2] show the amounts of organic acids in the waters of different artesian wells and springs.

Source of Sample	*Parts per Million Organic Acid*[3]	*Authority*
Bladen Springs, Alabama	2.7	R. T. Brumby
Trafalgar Square artesian water, London	3.3	Abel & Rowney
Cambray Spring, Cheltenham	5.4	Abel & Rowney
Bristol, England	34.9	Herapath
Eckheltz Spring, Ronneby, Sweden	18.1	Hamberg
Saint Boes, Pyrenees	4.8	Garrigon
Healing Spring, Bath County, Virginia	1.8	W. E. A. Aikin
Chalybeate Springs, Minneapolis, Minnesota	11.03	S. D. Hayes

[3]Recalculated by the writer.

As these acids are readily decomposed, it is probable that the CO_2 in many spring waters, particularly those of thermal springs, comes from the breaking down of the acids to CO_2 and water, which of course would increase the solvent action in the case of acids containing more than one carbon atom, but which would obliterate the evidence of the part played by the original acid in chemical erosion.

A molecule of organic acid carried into a limestone by ground water will dissolve as much calcite as a molecule of carbonic acid under the same conditions. This is shown by the reactions:

$$2CaCO_3 + 2C_2H_4O_2 \rightarrow Ca(C_2H_3O_2)_2 + CaH_2(CO_3)_2$$

$$2CaCO_3 + 2H_2CO_3 \rightarrow 2CaH_2(CO_3)_2$$

[1]*Proc. Amer. Assoc. Adv. Sci.* (1879), p. 338.

[2]*Ibid.*, p. 337.

The carbonic acid released by the reaction between the organic acids and the limestone will be a more efficient solvent than that obtained from the atmosphere because of its formation in very intimate contact with the limestone.

EXPERIMENTAL WORK

In order to obtain some idea of the kinds of acids generated and the amount of acid which could be produced in a definite period of time, a four-liter separatory flask was filled with dry leaves, most of which were elm, though a few were maple. To inoculate the material in the flask with bacteria, 25 grams of surface soil were washed in 100 cubic centimeters of distilled water. This mixture was then decanted and 25 cubic centimeters of the solution were introduced into the flask. The remaining space in the flask was filled with distilled water, and the flask was then corked, with the exception of a small opening to permit the escape of the gases which might be generated. The flask was kept at room temperature and pressure for a period of 215 days.

On the second and third days of the experiment, gas was given off in large quantities and the contents of the flask had a sour odor very similar to the odor of ensilage. This odor was probably due to the presence of small quantities of acetic and lactic acids, although the solution was still neutral to litmus. By the seventh day gas was not coming off in such profuse quantities, but bacterial action was indicated by the movement of gas bubbles within the flask. At this time the solution was acid to litmus and had a strong, rancid, slightly sour odor suggestive of old sour milk or stale butter. These odors were probably due to the presence of lactic acid and probably some butyric acid. A small amount of the liquid was drawn off and poured over powdered calcite. The calcite effervesced readily in the liquid.

The acid solution was first titrated after 41 days and its normality was 0.1093. Titrations were made at more or less regular intervals thereafter.

The following table (p. 1472) gives the results obtained.

These results show that a considerable amount of acid is generated in a relatively short period of time, and, furthermore, that there is a peak of acidity, which was probably reached before the first titration was made.

The continuous decrease in the acidity of the solution was due to the fact that the acid-forming bacteria became dormant, and the acid was decomposed into carbon dioxide and water by non-acid-forming

Number of Titration	*Time in Days*	*Normality of Acid*
1	41	.1093
2	99	.0501
3	110	.0234
4	120	.0213
5	132	.0202
6	142	.0090
7	153	.0069
8	163	.0059
10 grams gum arabic added	169	.....
9	183	.0127
10	215	.0199

bacteria which were able to exist and function in the acid solution. The dormancy of the acid-forming bacteria was due to two causes. First, they were unable to thrive under the toxic conditions which existed as a result of waste products generated by themselves. This fact was proved by another experiment, described in this paper, in which the acids were partially neutralized as they were formed. Second, the dormancy was due partly to depletion of the food supply. In the foregoing table it will be noticed that at the time of the eighth titration the normality of the acid was 0.0059, while at the time of the ninth titration the normality was 0.0137, which was the first upward trend of the normality after the beginning of the experiment. Six days after the eighth titration was made, about 10 grams of gum arabic were placed in the flask. Within 48 hours after the introduction of the new food supply, large quantities of gas began to come off, and gases continued to be given off for some time. This fact indicated that the acid-forming bacteria had renewed their activities, and later titrations showed an increase in acidity.

In order to obtain the peak of acidity, a second flask was prepared with leaves from the same source as those used in the first experiment. The inoculating bacteria, however, were not obtained from soil from the same locality as those used in the first experiment.

The data for the experiment and the results obtained are as follows.

Number of Titration	*Time in Days*	*Normality of Acid*
1	15	.0544
2	25	.0661
3	35	.0563
4	45	.0485
5	57	.0465
6	67	.0143
7	78	.0179

The acidity is considerably lower than that obtained in the first experiment. No explanation can be given except that the soil sample in this experiment may have contained fewer forms of acid-forming bacteria than the soil used in the first experiment. This explanation seems entirely reasonable in view of the fact that Omelianski and Kouvine obtained a fairly wide variation in the amount of acid produced by different bacteria.

Because the acidity, on reaching a certain concentration, checked the acid production, the following experiment was performed to determine the result of neutralizing the acids as rapidly as they were formed.

The data and the results are as follows:

	Grams
Leaves	400
$CaCO_3$	15
Distilled water	enough to fill flask
Inoculating solution	25 cc.
$CaCO_3$ added after 9 days	200
Distilled water added after 9 days	100 cc.
$CaCO_3$ added after 65 days	100

Number of Titration	*Time in Days*	*Normality of Acid*
1	9	Acid to litmus
2	29	.008
3	35	.0183
4	57	.0150
5	67	.0127
6	78	.0065
7	88	.0129
8	108	.0092
9	143	.0129

These results, though they fluctuate in a somewhat irregular manner, clearly indicate a continuous acid-producing process, as long as the acids formed are not allowed to accumulate. The accumulation of acids in nature could be prevented by frequent rains, which would cause flooding of the small pools or puddles in which the reaction was taking place, or by normal run-off.

Another experiment was performed to determine the extent of bacterial activity, if any, in an alkaline solution. After a period of 85 days the solution in the flask used for the second experiment was made alkaline to litmus with *NaOH*, though no great excess of the base was used. After the *NaOH* had been in the flask for 8 days, the solution was titrated and found to be only slightly acid. This showed that acid-

forming bacteria were unable to generate appreciable quantities of acids in an alkaline solution. After 58 days, titration showed acidity of less than 0.001 *N*.

The action of these acids on calcium carbonate is somewhat variable. Although the acids developed in the first flask dissolved calcite readily, it was found that the acids remaining in the flask after stimulation of the bacteria by gum arabic would not dissolve calcite even on boiling.

In the third flask acids were developed even in the presence of calcium carbonate and attained an acidity of nearly 0.02 *N*.

This action is explained by the fact that some of the acids developed are weaker than carbonic acid and do not affect carbonates, or else the calcium salts of these acids are insoluble.

Although large quantities of gas were given off, it was found impractical to collect this gas throughout a prolonged period. It was frequently noticed that the gas pressure developed was considerable and the flasks frequently overflowed in spite of the fact that a trap to collect the water was set about 10 inches above the surface of the water in the flasks. In the second experiment 500 cubic centimeters of gas, mostly carbon dioxide, was collected during the first 24 hours, after which the flask overflowed and the gas was lost.

CONCLUSIONS

These experiments demonstrate at least four conclusions.

1. Soil bacteria possess the ability to generate acids which are capable of dissolving calcium carbonate.

2. Carbon dioxide is generated in large quantities as a result of bacterial decomposition of plant material and also as a result of the reaction between the acids generated and calcium carbonate.

3. The bacteria become dormant when the solutions are made alkaline.

4. The time involved in the bacterial decomposition of plants is sufficient to allow the percolation of solutions containing bacteria to considerable depths before toxic conditions are set up.

It may thus be seen that solutions containing acids and carbon dioxide may percolate downward through limestone and that the solvent action of these solutions is carried on from the surface of the earth to the water table. At the latter depth the solutions in contact with carbonates become alkaline, and reactions between them and the limestone probably cease. Not only do the solutions carry carbon dioxide into the rock, but carbon dioxide is generated within the rock itself, and this carbon

dioxide, being in intimate contact with the rock, may well exert more effective action than atmospheric carbon dioxide which has been carried down by rain.

In making a quantitative estimate of the result of bacterial action, great difficulty is encountered. No estimate of the amount of organic acid carried into the limestone is possible.

In the Kentucky River basin, which is largely underlain by limestone, Dole and Stabler[1] estimate that, on an average, 164 tons of material are removed per square mile per year. On recalculating the analysis of Kentucky River water given by Clarke[2] on the assumption that the calcium is in the form of carbonate, it may be shown that 84 tons of this material are calcium carbonate.

As is demonstrated in the experiments here described, the average maximum acidity obtained by bacterial action was about 0.7 *N*, of which acids with a normality of 0.57 *N* would be effective in dissolving limestone. The average annual rainfall in the Kentucky River basin is about 30 inches and if one-third of this amount sinks into the ground and becomes as strongly acid as the solutions developed in the laboratory, it will dissolve 1,867 tons of limestone per square mile per year, or 23 times the amount actually dissolved. Obviously this acidity can not be obtained in nature.

On the other hand, organic acids having a strength of ten parts per million would, if completely neutralized, remove more than 5 tons per square mile per year or about one-seventeenth of the amount actually removed. As artesian wells and springs commonly contain this amount of organic acid,[3] it can be seen that the actual efficiency of organic acids in nature lies somewhere between the two extremes, and that the solvent action of acids generated by bacteria may be responsible for much of the solution of limestone taking place in nature.

Bacterial action, through formation of organic acids, must be much more effective in making limestones porous than atmospheric carbon dioxide. The effect of the latter is exerted largely on the surface of the rock, but the acids and carbon dioxide generated by bacteria can penetrate the rock deeply along openings, and, by removing calcite from the interior, may make the rock porous.

[1] *U. S. Geol. Survey Water Supply Paper 234* (1909), p. 87.

[2] "The Data of Geochemistry," *U. S. Geol. Survey Bull. 695* (1920), p. 79.

[3] *Ibid.*

GEOLOGICAL NOTES

SANDSTONES IN THE UPPER PART OF THE ARBUCKLE LIMESTONE, OKLAHOMA[1]

As the party, consisting of the writer, Norval Ballard, and Ross Maxwell, were studying various outcropping sections of the Simpson formation in the Arbuckle Mountains during the past field season, while studying the contact between Simpson and Arbuckle, several sandstones were found in the upper part of the Arbuckle limestone. This discovery is very significant because only sandy shales instead of good sandstones crop out at these upper Arbuckle horizons on the Ardmore-Davis road, and particularly because the so-called "Siliceous lime" and the production in the Oklahoma City field have been placed tentatively in the upper part of the Arbuckle formation.

These sandstones are exposed best for study in Sec. 36, T. 2 S., R. 3 E., in the pasture on the R. N. Hale farm about 12 miles south of Sulphur, Murray County. At this locality thin conglomerates at the base of the Simpson, the typical Arbuckle gastropod bed, and the upper Siliceous limestones are well developed. The dip ranges from 12° to 15° SW., and the thickness of the successive sandstones, beginning at the top, is 3, 5, 52, 12, and 4 feet, as shown in the appended section (Fig. 1). The conglomerates and upper limestones are exposed best near the southern edge of the open pasture, but the sandstones and intervening limestones are exposed best about 80 rods farther north.

The sandstones seem to be very pure, containing little if any clay. C. A. Merritt has studied some of these sands briefly, and has found that those in the region south of Sulphur range in diameter from 0.1 to 0.6 millimeter and that those north of Connerville range from 0.08 to 0.4 millimeter. In most samples the grains are well rounded, though the larger grains north of Connerville are somewhat angular. Many of the grains are pitted. No extended comparison has been made of these Arbuckle sandstones with those of the Simpson, but from the brief studies pursued, they seem to measure slightly larger in diameter than the Simpson sands.

[1]By permission of the Oklahoma Geological Survey.

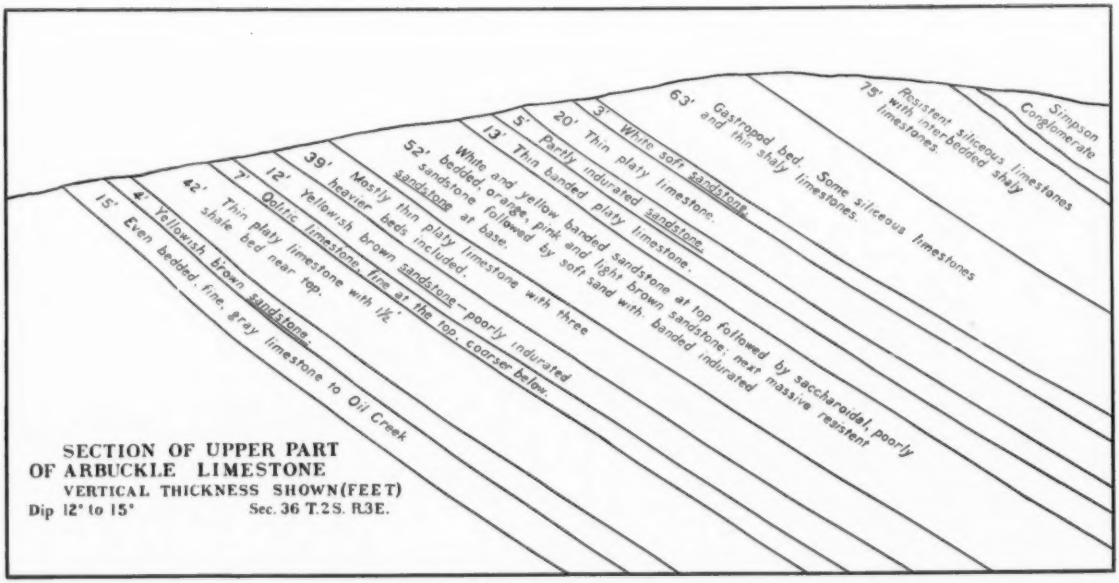
Simpson Conglomerate
75' Resistent siliceous limestones with interbedded shaly limestones.
63' Gastropod bed. Some siliceous limestones and thin shaly limestones.
3' White soft sandstone.
20' Thin platy limestone.
5' Partly indurated sandstone.
13' Thin banded platy limestone.
52' White and yellow banded sandstone at top followed by saccharoidal, poorly bedded, orange, pink and light brown sandstone, next massive resistent sandstone at base.
39' Mostly thin platy limestone with three heavier beds included.
12' Yellowish brown sandstone—poorly indurated
7' Oolitic limestone, fine at the top, coarser below.
42' Thin platy limestone with 1½' shale bed near top.
4' Yellowish brown sandstone.
15' Even bedded, fine, gray limestone to Oil Creek
SECTION OF UPPER PART OF ARBUCKLE LIMESTONE
VERTICAL THICKNESS SHOWN (FEET)
Dip 12° to 15°
Sec. 36 T.2S. R.3E.

FIG. 1

On the southwest limb of the Arbuckle anticline on the east side of the road 13 miles south of Sulphur, a sandstone 38 feet thick crops out 287 feet below the top of the Arbuckle. About 4 miles southeast of this last locality, where Oil Creek crosses the Arbuckle-Simpson contact, a sandstone holds a thickness of 15 feet for at least ¼ mile on either side of the creek, where it is 278 feet below the top of the Arbuckle. On the south end of the southward-plunging Plateau anticline 4 miles northeast of Woodford, there are five sandstones ranging from 5 to 12 feet in thickness in the interval between 130 feet and 340 feet below the top of the Arbuckle. Also, one thin sandstone 5 or 6 feet thick was noticed in Sec. 5, T. 2 S., R. 1 W., 5 miles east of Pooleville, on the southeast side of West Spring Creek about 100 feet below the top of the arbuckle.

Several soft sandstones in the vicinity of Connerville, which commonly have been credited to the Simpson, seem now to belong to the Arbuckle. This is true of the sandstone 1 mile north of Connerville and probably also of a second sandstone 1½ miles northeast of Connerville. Doubtless, also, several of the poorly indurated sandstones south of Connerville will be found to belong to the Arbuckle rather than to the Simpson.

CHARLES E. DECKER

NORMAN, OKLAHOMA
October 8, 1929

KETTLEMAN HILLS OIL FIELD, CALIFORNIA[1]

The three domes which make up the Kettleman Hills uplift are arranged *en échelon* and extend about 40 miles along the general line of folding which comes out of the Coast Ranges at Coalinga and extends 75 miles south to the south end of the Lost Hills field. Oil was discovered at Coalinga in 1890 and at Lost Hills in 1910. Wells were drilled on the North dome at Kettleman as early as 1895, and at least as many as thirty were drilled before the Milham Exploration Company's Elliott No. 1, in the SE. corner of Sec. 2, T. 22 S., R. 17 E., came in unexpectedly in October, 1928, flowing 3,600 barrels of 60°-gravity oil and about 70,000,000 cubic feet of wet gas, from a total depth of 7,100 feet. Since that completion about fifty operations have been commenced, most of them on the North dome. Four wells in addition to the discovery well have produced varying amounts of oil and large quantities of gas, the

[1]Published by permission of the Amerada Petroleum Corporation: a report on developments in the field by E. H. Musser, in *Summary of Operations, California Oil Fields* (San Francisco), Vol. 14, No. 5, November, 1928 (issued in September, 1929).

largest to date being the Continental Oil Company's No. 12-8, an offset to the Elliott No. 1, and located in the NW. corner of Sec. 12, T. 22 S., R. 17 E. It was completed in September, 1929, and has produced as much as 6,900 barrels of oil and 150,000,000 cubic feet of gas. The smaller wells have been mudded off and deepened. It was at first thought that the discovery well was producing from approximately 7,000 feet, but subsequent wells have shown that the upper part of the sand is productive, although the larger wells are those that have taken in the most sand.

STRATIGRAPHY

The surface beds along the axis are marine Etchegoin (Lower Pliocene), which plunge under the fresh-water Tulare (Lower Pliocene) on the flanks. Although the section from the surface to the producing sand is made up of four distinct lithological members, dividing lines between them are not well defined. This gradational change makes it difficult to measure the exact thicknesses of the formations, or to prepare accurate subsurface maps of them. The formations in order from the surface down are Etchegoin, Jacalitos (uppermost Miocene to Lower Pliocene), Santa Margarita (Upper Miocene), and Maricopa shale (Middle Miocene) which lies immediately over the producing sand. Of the several contacts, that between the Santa Margarita and the Maricopa can be recognized more satisfactorily than any other contacts higher in the section. The formations above the Maricopa are approximately 4,800 feet thick on top of the North dome. This thickness increases toward the south, probably reaching a maximum at the Middle dome, and from there south decreases to a minimum of 400 feet at Lost Hills. The Maricopa is 4,000 feet thick at Lost Hills, 3,000 at the South dome, 1,500 at the south end of the North dome, 1,200 at the north end of the North dome, and not present at Coalinga, although its absence here is no doubt due in part to overlap. This rapid convergence toward the north has shifted the subsurface "high" on the North dome north of the surface "high." What effect it will have on the other two domes remains to be seen. The producing sand is generally conceded to be Temblor in age, although formerly described as "Vaqueros." It is approximately 900 feet thick, and is broken by streaks of shale, and in some wells contains beds of re-worked serpentine, corresponding with the "Big Blue" of Coalinga.

STRUCTURE

Although the North and Middle domes are topographically one unit, it is evident from surface structure that there is a saddle separating

them, as well as one between the Middle and South domes. The South dome, however, can not be separated from the Lost Hills field, either on surface or subsurface evidence. Of subsurface structure little is known except in the North dome, where several wells have reached the Maricopa shale, and about twelve have penetrated the producing sand. From this data the subsurface map (Fig. 1) was prepared. Two features of interest are to be observed from this map.

The first of these is the shift of the structure toward the north, due to convergence in that direction. It is now thought that there is approximately 1,200 feet less in the section between the upper Mulinia zone (middle Etchegoin) and the Temblor on the north end of the North dome than on the south end. Furthermore, although the Maricopa is somewhat higher on the South dome than on the North, the only well to reach the Temblor on the South dome found it about 1,200 feet lower than on the North dome. This change in thickness is due in the Maricopa to the general thickening of the Tertiary section in the San Joaquin Valley on the south. The changes in thickness in the overlying section, however, are due to removal by erosion, as well as to southward divergence. Thus the thinning in the Santa Margarita and overlying formations from the Middle dome northward is due to convergence, and the thinning toward the south is due to erosion, which reaches its climax at the north end of the Lost Hills field, where the Maricopa comes within a few hundred feet of the surface. From this evidence it seems probable that the sand will be found to be deepest on the Middle dome, although this structure has the most nearly perfect surface closure.

The second point of interest is the steeper dip found on the southwest side of the North dome. An indication of this is to be observed on the surface, the maximum dip on the northeast flank being 31°, that on the southwest 45°.[1] From the meager data available, this asymmetry seems to persist with depth.

Considerable surface faulting is found on the North dome. Although opinion is divided as to the possibility of this affecting the sand, the weight of evidence opposes a probability, since the nature of the faulting indicates that it was caused by dropped, wedge-shaped blocks along the crest, which have resulted from the failure of the roof of the dome.

FUTURE DEVELOPMENT

By agreement with the Department of the Interior, no great production or development will be allowed on any of the domes until 1931,

[1]Ralph Arnold and Robert Anderson, "Geology and Oil Resources of the Coalinga District," *U. S. Geol. Survey Bull. 398* (1910), p. 332.

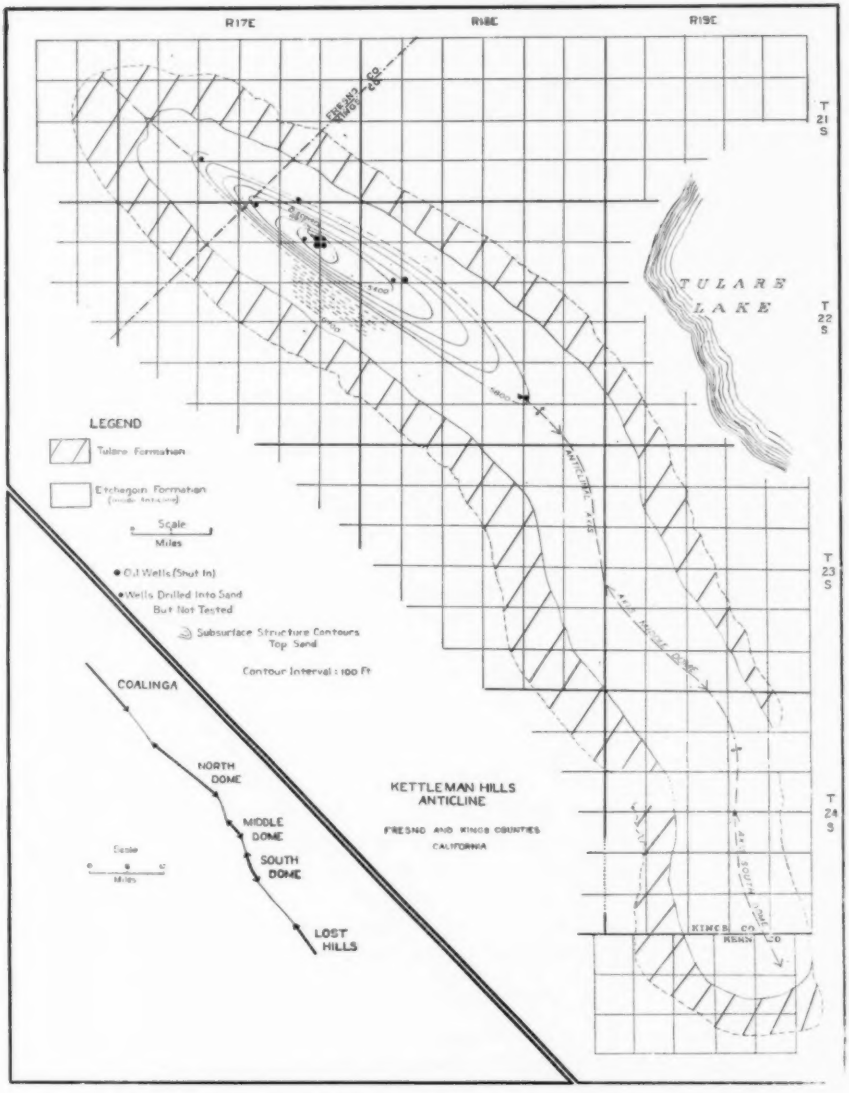

FIG. 1.—Map of Kettleman Hills showing areal geology as mapped by Arnold and Anderson in *U. S. Geol. Survey Bull. 357*, and subsurface geology of the North dome by the writer. The crests of the Middle dome and South dome are indicated by arrows. The insert map shows the position of Kettleman Hills on the line of folding from the Coalinga oil field to the Lost Hills oil field.

Subsequent note—The wells shown as "shut-in" when this map was drawn (October 1) are now wide open (October 21, 1929).—EDITOR.

unless market conditions necessitate a change of policy. It is thought that 1 well to 20 acres may suffice to drain efficiently such high-gravity oil, and most locations are made with this in mind, but so that the number of wells can be doubled if found advisable.

Estimates vary, but it is generally thought that recovery will reach at least 50,000 barrels per acre. Production on the North dome has not been defined in any direction, but it is probable that the productive area will cover 10,000 acres. Production on the Middle and South domes is yet to be proved, and if it should be, it seems improbable that together they will cover as much area as the North dome.

E. H. McCollough

401 S. Cochran Avenue
Los Angeles, California
October 1, 1929

RESEARCH NOTES

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The purpose of the Research Committee is the advancement of research within the field of petroleum geology. If members working actively in research on particular problems care to register with the Research Committee, the committee will be glad to aid them in any way it can and put them in touch with other men who are, or have been, working on similar or allied problems and can perhaps effect some integration of the research work of the Association. If the younger, or older, members of the Association, who are doing or preparing research for publication, will come to any member of the Committee, he will be very glad to offer whatever advice, counsel, or criticism he can in regard to the research, its prosecution, or its preparation for formal presentation. The Committee would be glad to have members formulate and present to it suggestions in regard to research problems and programs.

AN ALGAL LIMESTONE IN SOUTHERN CALIFORNIA

The limestone bed from which this specimen (Fig. 1) was taken is cut by tributaries east of Santa Ynez Canyon in the San Vicente y Santa Monica Grant, Los Angeles County. If the public land surveys were projected over this area, the limestone bed would lie in T. 1 S., R. 16 W., extending from the SW. ¼ of Section 15 northwesterly across the northeastern part of Section 16.

The limestone bed is 60-100 feet thick, crops out along the strike for more than 1 mile, and dips approximately 35° SW. A fine-grained siliceous clay shale underlies and overlies the limestone. On the east and on the west faults striking north and south bound the block within which the limestone lies. Cretaceous sandstones lie on the east of the block and Miocene sandstones on the west. The limestone is probably Eocene. Analyses of many samples show that it contains 95 per cent or more of calcium carbonate.

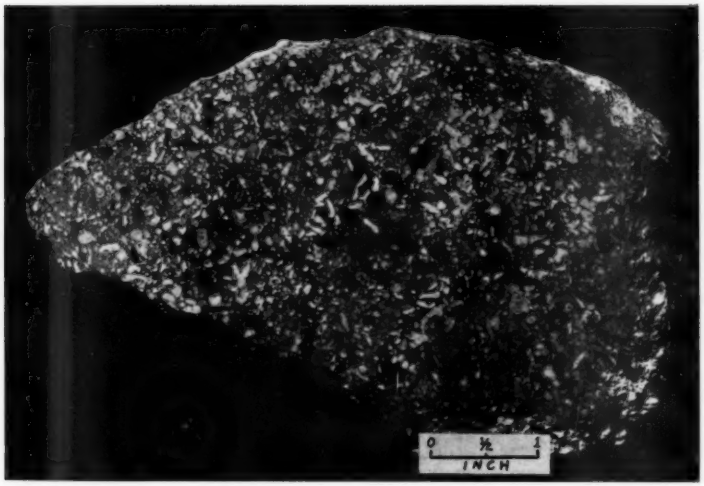

FIG. 1.—Algal limestone near Santa Ynez Canyon, Los Angeles County, California.

The photograph shows a polished surface.

S. L. GILLAN

812 SUBWAY TERMINAL
LOS ANGELES, CALIFORNIA
September 17, 1929

REVIEWS AND NEW PUBLICATIONS

Annotated Bibliography of Economic Geology (for 1928). Prepared under the auspices of the National Research Council. Published by Economic Geology Pub. Co. Urbana, Illinois. Vol. 1, Nos. 1 and 2 (July, 1929), 380 pp., 8vo paper. Price, $5.00.

Owing to the efforts of Waldemar Lindgren, formerly of the Division of Geology and Geography of the National Research Council, the first volume of this invaluable bibliography has been published. It has been prepared under the auspices of the Council. Henceforth, each volume will consist of two numbers, published in March and July, at a price of $3.00 each, or $5.00 a year. The Economic Geology Publishing Company has undertaken the printing and distribution. At the end of 1928 nearly $20,000.00 had been obtained, which should be sufficient to conduct the enterprise for five years at least. Additional subscriptions at any time will be welcomed.

Sections of the bibliography are prepared under different chiefs, including foreign geologists, and the reviews embrace publications in all languages. Professor W. V. Howard,[1] of the University of Illinois, prepared the section on petroleum and gas for Volume 1. This section embraces 73 pages and 476 titles. This bibliography is more extensive than any of those in current periodicals and should be in all libraries. Professor Lindgren is to be congratulated on the initiation of this worthy project.

S. P.

TULSA, OKLAHOMA
September 30, 1929

"Oil and Gas in Alabama." By D R. SEMMES. *Geol. Survey Alabama Special Rept. 15* (University of Alabama, 1929), 408 pp., cloth 8vo. Price, $1.15.

This comprehensive treatise on oil and gas possibilities in Alabama is a welcome contribution to the knowledge of the structural geology of the state. The first 40 pages are devoted to an up to-date, brief statement of the origin and accumulation of oil and of the methods now being employed to find structure favorable for drilling. Northern Alabama is described in 160 pages, southern Alabama in 200 pages. A number of instructive and accurate structure contour maps, a map showing the location of all the wells drilled in the state, and tabulations listing all wells and giving available information about them accompany the text. The state geologist and author are to be complimented on this most useful volume.

Owing to the absence of the author when the volume was in press, a few errors will be found. On page 286 the Waskom gas field, on page 291 the Keechi

[1]Suggestions or comments or any assistance in abstracting articles will be appreciated by Professor Howard.—EDITOR.

salt dome, and on page 377 the Alahoma Oil Company's well are difficult to recognize because of incorrect spelling. The small colored geological map of the state, published in 1920, unfortunately does not accompany this report.

It is interesting to notice (p. 370) that the Appalachian Mountains trend southwest or west under the Coastal Plain and (p. 292) that salt domes will probably not be found in Alabama because of the location of the late Paleozoic geosyncline.[1]

S. P.

TULSA, OKLAHOMA
September 30, 1929

"Preliminary Report on the Kettleman Hills Oil Field." By E. H. MUSSER. Report dated April 1, 1928, printed in "Summary of Operations, California Oil Fields, Monthly Chapter, Fourteenth Annual Report of the State Oil and Gas Supervisor" issued by *Department of Natural Resources, Division of Mines and Mining* (San Francisco), Vol. 14, No. 5 (November), 1928).

This report was printed at as early a date as possible on account of the great public interest in the Kettleman Hills area. The report describes the topography, geography, discovery of oil, geology, history of development, oil and gas production, drilling methods and costs, land ownership, and underground data relating to the field. Much detailed information is presented and the reader will find the report a very good account of the state of knowledge of the field at the date of publication. Plate "*A*," which is a general map of the field in relation to the geologic structure, is to be commended.

The author's discussion of the geology reveals the loose usage of formation names current in the San Joaquin Valley. The classification of Arnold and Anderson[2] is followed. For the Kettleman Hills this is proper, but the reader should beware of comparing the Kettleman Hills section with that of the Sunset-Midway district on the basis of formation names. For example, the Etchegoin of the Kettleman Hills is known to contain about 2,000 feet of beds which are ordinarily referred to the Paso Robles in the Sunset-Midway district, and the Jacalitos of the Kettleman Hills corresponds in general with the Etchegoin of the Sunset-Midway. The author follows the classification of Arnold and Anderson for the productive Lower Miocene sands, using the name Vaqueros, and notes that this name has been replaced by Temblor in most recent work. The use of the name Maricopa to denote the 1,200-1,500 feet of siliceous brown shale above the productive sands is to be discouraged. The type Maricopa, of the Sunset-Midway, is a catch-all for the siliceous shales ranging in age from post-Santa Margarita to Temblor. The so-called Maricopa of the Kettleman Hills is of Santa Margarita or probably of post-Santa Margarita age, according to the work of Arnold and Anderson[3] on the adjacent section at Reef Ridge.

[1] Arthur Keith, *Bull. Geol. Soc. Amer.*, Vol. 39 (1928), Fig. 20.

[2] "Geology and Oil Resources of the Coalinga District," *U. S. Geol. Survey Bull. 398* (1910).

[3] *Op. cit.*, p. 95.

Several papers dealing with the stratigraphy of the Kettleman Hills area are now being prepared for presentation at the fall meeting of the Pacific Section of the American Association of Petroleum Geologists. The reader is advised to wait for the publication of these papers before coming to any fixed notion regarding the geologic age of the formations penetrated by drilling wells on the North dome. For the present it is safer to visualize the average well as penetrating about 5,000 feet of sands and blue shales, and about 1,200-1,500 feet of hard, brown, siliceous shales, before entering Miocene sands containing the production.

The author commits the common error of assuming that the numerous faults exposed at the surface on North dome will not continue with depth. We now know that several of these faults affect the position of the top of the productive sand. Faults have been cored in several wells below 5,000 feet. Detailed surface mapping does not verify the author's statement that the various domes may be separated by faulting. The domes have the *en échelon* arrangement so common in the structure of California fields.

GEORGE M. CUNNINGHAM

BAKERSFIELD, CALIFORNIA
October 1, 1929

"Los Metodos Geofisicos de Prospeccion" (Geophysical Prospecting Methods). By J. G. SINERIZ. *Boletin del Instituto geologico de España* (Madrid). Tome 10, Tercera Serie, 498 pp., 215 figs.

This book was presented at the last International Geological Congress at Pretoria. The author, J. G. Sineriz, has been elected president of the International Commission of Geophysics. His work has been published as a result of the inquiries conducted by the geological survey of Spain about geophysics, in accordance with a resolution of the former congress at Madrid.

Dr. Sineriz has been in charge of the organization of the geophysical section of the Spanish Geological Survey and the supervision of the geophysical studies which have been made in that country during the last two years.

This work has included the application of all the different geophysical methods—torsion balance, electrical prospecting, seismograph, and magnetism. Most of the surveys have been made by specialists in each method. In this way, the author has had the very rare opportunity to study and compare the application of all the different methods. This fact gives an extraordinary interest to his book. It is not only a text book giving all the necessary developments about the principles, formulae, and apparatus used in geophysics, but it is also a very valuable source of information about the practicability, the applications, and the results of the different methods.

Of course, it is necessary to know the scientific principles of applied geophysics, but it is more important for the geologist or the mining engineer to know exactly what he can expect from the different methods. In this respect, the comparison which the author makes of the results of all the geophysical methods used in the same area, as the coal basin of Villanueva de las Minas, is especially interesting.

The book also gives much new and valuable information concerning seismic and electrical methods.

To conclude, we can say that, among the very few text books of geophysics which have been published so far, the work of Sineriz is of outstanding interest, and it is the most up to date. We can only compare it with the book of Ambronn, *Applied Geophysics*, but Sineriz seems to be less theoretical and to be more acquainted with the practical problems of the application in the field.

A French translation of the book is already in preparation and an English translation will certainly follow.

P. CHARRIN

PRETORIA, SOUTH AFRICA
August, 1929

Sedimentary Petrography (with Special Reference to Petrographic Methods of Correlation of Strata and to Subsurface Oil Geology). By HENRY B. MILNER. 2nd (Revised and Complete) Edition. Thomas Murby & Co., 1, Fleet Lane, E. C. 4, London. D. Van Nostrand Co., 8 Warren Street, New York (1929). 502 pp., illustrated, cloth, 5½ x 7½ inches. Price, $8.00.

The aim of this book is to provide "a comprehensive text book of petrology of sediments, both incoherent and consolidated." All who have attempted to use the petrologic characteristics of sediments as criteria for their identification and correlation have felt the need of such a text book. This new volume of Milner's is one which all students of sediments, whether in academic or other spheres of interest, will find invaluable. In preparing the book, the author has given cognizance to "the impetus universally accorded to detailed studies of sedimentary rocks by the exigencies of oil field developments" with the belief that by focussing attention to detail thus implied * * * its value in the hands of all investigations of sedimentary deposits" will be increased.

"Questions concerning the genesis of a sediment, involving not only ideas as to its source of origin, but also definite conceptions of its mode of transport and disposition, the nature of environmental and climatic conditions at the epoch of its formation—together with the pertinent aid which the subject affords to paleogeographical restoration—are all embraced by systematic petrographic examination of a series of deposits." As a corollary to this larger application of sedimentary petrography, it has been found by experience that individual sedimentary units can be identified petrographically and "both principles and practice of correlation and differentiation of sediments, either by heavy minerals or by thin sections, have been stated in the light of * * * extensive experience, especially in connection with subsurface (exploitation) oil geology." Actual examples of the correlation and differentiation of sedimentary units by the application of petrologic principles are given.

This second (revised and complete) edition embodies certain sections of the original volume (*An Introduction to Sedimentary Petrography*, 1922), much of the supplement (*Supplement to an Introduction to Sedimentary Petrography*, 1926)—both subjected to critical revision—and a large amount of new matter.

Chapter 1 is an "Introduction to the Study of Sedimentary Rocks." The author states: "the determination of the mineral constitution of sediments is but a means to an end; it is the first stage toward unravelling their history."

Chapter 2 is entitled "Surface and Subsurface Samples, Storage and Records." Different kinds of samples are described, containers, storage, sample-indexing, et cetera. A specimen well sample card, as designed and used by the author, is given.

Chapter 3 deals with "Laboratory Technique." This chapter is particularly valuable to the student just beginning his study of sedimentary petrography. The reviewer believes that each experienced worker will develop his own technique and filing system.

Chapter 4 deals with "Microscopical Examination of Sediments." Various types of microscopes are described. Under the heading "Systematic Examination of Detrital Sediments under the Microscope," Milner lists the optical properties that can be found for any mineral grain and describes the methods to be used in determining the optical properties. This is a particularly valuable contribution, since most text books of petrography deal with this subject from a thin-section point of view.

Chapter 5 gives "Quantitative Data." Here are listed primary structures, porosity, ratio of absorption, mechanical analysis, percentage of heavy minerals, physical properties of mineral grains, et cetera.

Chapter 6 gives "Diagnostic Properties of Sedimentary Rock Minerals." Of the 72 minerals fully described, 55 are figured. "Essential, especially optical, properties of the minerals are discussed in detail, the desire being to give the fullest and most varied data leading in each case to positive diagnosis." At the end of this chapter, 25 "sedimentary rock minerals of sporadic and local occurrence" are listed.

Chapter 7. "The Petrography of Consolidated Sediments." In this chapter "an attempt is made to describe systematically every familiar type on the basis of logical classification." Seventy photomicrographs of thin sections of typical rocks are included.

"In view of the importance of 'thin section' correlation of compact rock-types in exploitation oil-geology * * * their treatment here departs from custom in its bias to the technique implied by that particular application."

Chapter 8 discusses the "Principles and Practice of Differentiation and Correlation of Sediments by Petrographic Methods." Sub-headings in this chapter are as follows: The Geographical Cycle; Provenance; The Distributive Province; Relation of Sediments to Parent-Rocks; Conditions of Deposition; Technique of Application of Petrographic Methods; Schedule of Information to be Obtained from Heavy Mineral Assemblages; Deductions from Records; Special Cases and Difficulties; Thin Section Correlation; The Methods Applied to Igneous Rocks.

Chapter 9 gives actual "Examples of Differentiation and Correlation of Sediments by Petrographic Methods." Twelve "cases" are cited, six by Milner, the balance by workers in different parts of the world. This chapter is of value both to the worker whose superior has to be "shown" that the methods are practical, and to the beginner who wishes to know how to apply and interpret the petrologic information he has obtained.

Chapter 10, "The Bearing of Sedimentary Petrography on Paleogeographical Problems," presents some new ideas to those paleogeographers who believe that fossils are the only reliable paleogeographic criteria. Milner states:

"only where paleontological investigations are followed hand-in-hand with petrographical analyses can we expect to gain the fullest knowledge, enabling each step in the process of reconstruction to be made with a reasonable degree of accuracy."

Chapter 11, on "The Application of Sedimentary Petrology to the Study of Soils and Related Superficial Deposits" is written with the hope that it "will prove of value to agricultural chemists, physicists and mineralogists for whom soil investigations make common cause." This chapter has a special bibliography.

Appendix I. "Detrital Mineral Determination Tables. Method of Use." Nine tables are given: (1) Opaque Minerals, (2) Isotropic Minerals, (3) Colorless Anisotropic Minerals, (4) Yellow Anisotropic Minerals, (5) Brown Anisotropic Minerals, (6) Pink or Red Anisotropic Minerals, (7) Green Anisotropic Minerals, (8) Blue Anisotropic Minerals, (9) Mauve or Violet Anisotropic Minerals.

Appendix II lists "Certain Rock-Forming Minerals as yet Unrecorded from Detrital Sediments but to be Anticipated as Petrographical Research Proceeds."

Appendix III is the Bibliography.

FANNY CARTER EDSON

TULSA, OKLAHOMA
October 14, 1929

"Modern Instruments for Seismic Prospecting." By R. AMBRONN. *Eng. Min. Jour.* (New York), Vol. 128, No. 3 (July 20, 1929), pp. 93-99. Translated into English by E. U. von Buelow.

Dr. Ambronn announces a "new" type of seismograph which registers electrically the acceleration of the earth movement rather than the total movement registered by the mechanical seismographs. Because of the electrical registration, very high amplification is possible. Several receivers and the shot time line are connected to a multiple unit recording galvanometer and record on a single film. Time can be measured to 0.001 second. A considerable discussion is given of the advantages of an electric seismograph registering acceleration contrasted with the disadvantages of the mechanical seismograph registering total movement.

The assertions are made that seismographs used to date are mechanical seismographs; that the author's new seismograph has much higher sensitivity than the seismographs in use; that the ordinary ground unrest is avoided; and that explosive charges of the order of only 20-100 grams of dynamite per kilometer are sufficient to give clear records.

This paper reflects the same stage of development through which the American seismic method passed four years ago. The general type of instrument and method which he proposes have been standard in America for four years. More electric seismographs, registering acceleration, are in use in America than any other type. That type of seismograph and the method proposed by the writer already have to their credit twelve salt domes definitely proved

by drilling and many more which have not yet been drilled. Several types of American electric seismographs have very much greater sensitivity and possible amplification than they can use. Abundant ground unrest of sufficiently short period seriously to obscure the impact of the explosion waves is present and precludes the use of high sensitivity and amplification, although, of course, as the author correctly states, the unrest with a period longer than a few tenths of a second does not seriously affect the acceleration type of instruments. In this country, it has been found that the inexperienced introducers of a new type invariably stress the supersensitivity of their instrument and the small charge of dynamite required. As the controlling factor is the ground unrest and not the supersensitivity of the instrument, there is no reason to believe that the seismograph proposed by the author has any more effective sensitivity or can use any lower charges of dynamite than the present American electric seismographs. According to the standards of American practice, many of the seismograms illustrating the paper show an attempt to use too much amplification and not enough dynamite and would be thrown out as having too much ground or instrumental unrest.

DONALD C. BARTON

HOUSTON, TEXAS
October 11, 1929

"Über Rumänische Salztonaufbruche" (The Intrusive Salt-Clay Upthrusts of Roumania). By A. PUSTOWKA. *Beiträge zur Kenntnis der Tektonik Rumanien*, I, edited by Karl Krejci-Graf. *Neues Jahrb. für Min.* (Stuttgart), Beilage Band 41, Abt. B (1928), pp. 317-98.

This paper is designed to give a brief survey of the structural relations of the Roumanian salt domes to the Carpathians, of the relations of the salt domes to one another, and a brief description of many individual salt domes and anticlines of the southern sub-Carpathian zone. The paper comprises a discussion of:

A. The emplacement of the salt domes in the regional structure,
B. The stratigraphy,
C. The salt domes
   1. Within the area of the overthrust,
   2. In front of the edge of the overthrust, and
   3. Of the sub-Carpathian area of western Munteria and of eastern Munteria, and
D. The problem of the exotic blocks.

A bibliography of 40 titles is appended. The paper is illustrated by 37 text figures, chiefly cross sections, 2 plates of cross sections, and an excellent map of the southern Carpathian area of Munteria. This map and the sections evidently contain much hitherto unpublished material from the archives of the oil companies.

The salt domes (of old Roumania) are confined to the area in which the salt formations, Aquitanian, Burdigalian, and Helvetian, occur. The intrusively upthrust salt and accompanying clay and marl are of Miocene age. The genesis of these diapir folds is a function of tangentially directed thrust,

and of high mobility of the core beds. The order of occurrence and the division of the salt domes distinctly show their connection with the tectonics of the Flysch Carpathians. Erosion of the crest of the anticlines has aided and expedited the upthrust of the salt. The period of upthrust of the salt domes included the whole Pliocene.

DONALD C. BARTON

HOUSTON, TEXAS
October 11, 1929

"Magnetometer Survey of Louisiana." By L. SPRARAGEN. *Oil and Gas Journal*, Vol. 27, No. 46 (April 4, 1929), pp. 103, 110; Vol. 27, No. 48 (April 18, 1929), pp. 85, 96-97.

The survey is based on the U. S. Coast and Geodetic Survey observations, which, with few exceptions, were made only at the parish (county) seats. The vertical intensity is contoured with isogams of 100 gammas interval for the vertical intensity as observed and as corrected for the regional variation.

A vague reflection of some of the major structural features can be seen in some of the magnetic anomalies; the Sabine and Monroe uplifts show positive anomalies and the intervening geosyncline shows a negative anomaly; an east-west positive anomaly corresponds with the west half of the Sulphur-Lockport-Jennings salt-dome line. But on the other hand, the Many area shows as big a positive anomaly as the Sabine uplift and the area southeast of Lafayette and Baton Rouge; and the indications from the magnetic anomalies are contrary to the geology. The stations are so widely scattered that such studies are of very little practical value to the experienced geophysicist and are dangerous in the hands of a layman.

DONALD C. BARTON

HOUSTON, TEXAS
October 11, 1929

Paläontologisches Praktikum (Paleontological Methods). By O. SEITZ and W. GOTHAN. Julius Springer (Berlin, 1928).

A "Praktikum," according to Seitz and Gothan, is commonly a mere compilation of the technical methods, principles, and expedients used in carrying on some branch of scientific work. In preparing a paleontological Praktikum, however, they were confronted with the fact that observation during collecting is of prime importance for any further study of the fossils. This fact, the authors optimistically assume, is well understood by all professional paleontologists. The amateur, however, to whom the science has owed much in the past, has not kept pace with recent developments. For his sake, therefore, the authors embellish their Praktikum with a 40-page discussion of some recent investigations bearing on the interpretation of geological data. These are of interest not only to paleontological amateurs and professionals, but also to all students of the nature and origin of sedimentary rocks.

Starting with a historical sketch, the authors evaluate the work of William Smith, Cuvier, D'Orbigny, Oppel, and other pioneers. These men were inter-

ested only in morphology and stratigraphy. Aside from other unfavorable conditions, the theory of unchanging species, dominant at the time, barred them from considering many problems that now seem important. Even after *The Origin of Species* appeared, paleontologists were slow in applying the new ideas to their problems. As a brilliant exception, Hilgendorf, in 1866, published a thoroughly modern study of the varieties of *Planorbis multiformis* in the Steinheim fresh-water limestone. He observed accurately, collected intensively and bed by bed, rejected re-worked shells, and defined the phylogenetic series that were present in the formation. The excellent example set by Hilgendorf in this classic study was unfortunately neglected by most paleontologists during the next half-century. In recent years, however, it has been followed with brilliant success by a rapidly increasing number of workers, especially in Germany and Austria.

Even the older methods of correlation, by index fossils or by direct comparison of faunas, are giving way in favor of the biostratigraphic method. As defined by Wedekind, this is the method of making stratigraphic divisions with the aid of "form-series" on the basis of careful, bed-to-bed collecting. Quantity of material, relative abundance of species, and many other observational data are important for this work. When they are available, problems concerning facies and paleogeography may be attacked and often solved in a way that was impossible with the earlier methods.

Another of the newer developments is "paleobiology"—the word is due to Dollo—developed by Abel, Dacqué, and others. It is the science "which considers fossil forms from the viewpoint of comparative anatomy, and seeks to interpret them in terms of their environment." Paleobiologic methods include

1. Comparison of fossil forms with the most similar living forms,
2. Interpretation of the function of organs from the shape, et cetera,
3. Deductions as to the biologic relations of fossil forms from the character of enclosing sediments and the position of the fossils in them.

For the first and second methods reference is made to the work of Dacqué, Abel, and Johannes Walther. The last method has been used by several students. Weigelt, for example, has developed the new discipline of "biostratonomy," the task of which is to investigate the mechanical association of organic remains and their relation to enclosing sediments. It proceeds in two ways: by studying recent accumulations of shells, bones, and other organic materials, and by describing the position and distribution of fossils in the rocks. It contributes thus to the investigation of those factors of general geologic and biologic nature which were active in the accumulation of fossils and in the formation of sediments. Paleobiology here makes contact with the better known science of paleogeography.

Under the heading "Fossilization," the authors discuss many biostratonomic problems, particularly those concerned with mollusks, and give copious references to the work of Weigelt and others. They demonstrate the great importance of these problems and the possibility of solving many of them by sufficiently careful collecting and especially by thorough and accurate observation during the collecting. They also give many striking examples of the valuable data secured by Weigelt and other students from observations of modern

organisms in the process of becoming buried along sea coasts and river courses. In conclusion, however, they emphasize the fragmentary character of the data now available, and the necessity for a vast amount of additional work before general principles can be safely deduced. The important fact already demonstrated is that observation during the collecting of fossils is a necessity for paleontological progress in the future.

A few of the more important recent works to which frequent reference is is made seem worthy of being listed here.

Abel, *Lehrbuch der Paläozoologie.* Fischer (Jena, 1924).

Dacqué, *Vergleichende biologische Formenkunde der fossilen niederen Tiere.* Borntraeger (Berlin, 1921).

Diener, *Grundzuge der Biostratigraphie.* Deuticke (Leipzig und Wien, 1925).

W. Quenstedt, "Beiträge zum Kapitel Fossil und Sediment vor und bei Einbettung," *Neues Jahrb. f. Min.*, Beil. 58, Abt. B, p. 335.

R. Richter, "Flachseebeobachtungen sur Paläontologie und Geologie," *Senckenbergiana* 4 (1922), p. 103.

J. Walther, *Allgemeine Paläontologie.* Borntraeger (Berlin, 1919-27).

Wedekind, "Über Zonenfolge und Schichtenfolge," *Zentralblatt Min.* (1918), p. 268.

J. Weigelt, *Angewandte Geologie und Paläontologie der Flachseegesteine und das Erzlager von Salzgitter.* Borntraeger (Berlin, 1923).

Weigelt, "Über Biostratonomie," *Der Geologe*, Nr. 42 (November, 1927). Max Weg (Leipzig).

Weigelt, *Rezente Wirbeltierleichen und ihre paläobiologische Bedeutung*, Max Weg (Leipzig, 1927).

The last is a beautifully illustrated discussion of death, decay, and burial as geologic phenomena. Many of the author's observations were made in Texas. Still another of Weigelt's works, too recent to be cited in the Praktikum, is an interesting contribution to sedimentational literature: *Die Pflanzenreste des mitteldeutschen Kupferschiefers und ihre Einschaltung ins Sediment*, Borntraeger (Berlin, 1928).

In addition to the geological introduction, the Praktikum contains detailed instructions in methods of collecting, preparing, photographing, and studying animal and plant fossils. The discussion of micro-fossils, chiefly foraminifers and diatoms, is good; it recounts, apparently, all the methods that have been described for their study in German publications. There are 48 illustrations, many of them very instructive. The accounts of special methods for all sorts of purposes are so numerous as to be surprising to the layman, and to make him feel that any paleontologist is exceptional indeed who can read the book without learning something new and useful from it. So far as American readers are concerned, however, whether they are paleontologists or not, the chief interest of the book will probably lie in the contribution it makes toward bridging the gap that has too often existed between paleontologic pursuits and the interests of the ordinary geologist.

R. D. REED

ALHAMBRA, CALIFORNIA
October 12, 1929

RECENT PUBLICATIONS

ARKANSAS

"Geology of the DeQueen and Caddo Gap Quadrangles, Arkansas," by Hugh D. Miser and A. H. Purdue. *U. S. Geol. Survey Bull. 808* (1929). 195 pp., 9 figs., 18 pls., 1 insert map. Supt. of Documents, Washington, D. C. Price, $0.75.

CANADA

"Crude Petroleum in Alberta," by Theodore A. Link. *Oil Weekly* (Houston, Texas, October 11, 1929), pp. 205-6.

CROOKED HOLES

"New Surveying Device Shows Course of Crooked Holes." *Petroleum World and Oil Age* (Los Angeles, California), pp. 89-91, 152. 6 figs.

The first number (October, 1929) of the first volume of the new magazine *The Petroleum Engineer* (Tulsa, Oklahoma) has the following brief articles on crooked holes.

"Some Aspects of Straight Hole Drilling," by K. C. Sclater. Pp. 21-22.

"Some Outstanding Examples of Crooked Holes," p. 31. 1 fig.

"Drill Pipe Flexure and Crooked Holes," by W. P. Haseman. P. 49. 1 fig.

GENERAL

"Photographic Log may be Obtained with Device Used Abroad," by Th. Reinhold. *Oil Field Engineering* (Philadelphia, October 1, 1929), pp. 26, 27, 58. 3 photographs. 1 fig.

"Petroleum in 1927," by G. R. Hopkins and A. B. Coons. *U. S. Bur. Mines Mineral Resources of the United States* (July-August, 1929). Supt. of Documents, Washington, D. C. 593 pp. Price, $0.15.

MISSISSIPPI, ALABAMA, AND TENNESSEE

"Oil and Gas Possibilities in Three Southern States," by H. D. Easton. *Oil and Gas Journal* (September 26, 1929), pp. 173, 175, 177.

OKLAHOMA

The Oklahoma Geological Survey, at Norman, has issued the following publications.

"Oil and Gas in Oklahoma. Geology of Haskell, Latimer, Le Flore, and Sequoyah Counties," by J. A. Stone and C. L. Cooper. *Bull. 40-II* (August, 1929), 24 pp., 2 figs., 2 pls.

"Oil and Gas in Oklahoma. Geology of Okfuskee County," by J. Philip Boyle. *Bull. 40-KK* (August, 1929), 24 pp., 5 figs., 3 pls.

"Structure of the Ouachita Mountains of Oklahoma and Arkansas," by Hugh D. Miser. *Bull. 50* (October, 1929), 30 pp., 7 figs., 3 pls.

TEXAS

"Special Features of Core Drilling in the Salt Beds of Western Texas and New Mexico," by James S. Wroth. *U. S. Bur. Mines Information Circular 6156* (August, 1929). Publications Section, Bur. Mines, Washington, D. C.

"Comparison of Torsion Balance and Geologic Interpretations of Outline of Biue Ridge Salt Dome," by Jack Logan. *Oil Weekly* (October 11, 1929), pp. 37-41, 2 maps, 2 geologic sections.

"Study of Sub-Surface Conditions in Erath County, Texas," by R. O. LaNeve. *Oil Weekly* (October 11, 1929), pp. 179, 210. 1 map.

"Precise Leveling in Texas (revised edition), *U. S. Coast and Geodetic Survey* (1929). Order from Supt. of Documents, Washington, D. C. Price, $0.25.

WYOMING

"A Study of the Crude Oil Produced in the Salt Creek Field, Wyoming," by H. P. Rue and I. N. Beall. *U. S. Bur. Mines Tech. Paper 449* (July-August, 1929). Supt. of Documents, Washington, D. C. 27 pp., 5 figs. Price, $0.05.

TECHNICAL PERIODICALS

The following publications have been added to the list of *Bulletin* exchanges.

Bulletin of American Petroleum Institute (New York)

Mitteilungen aus dem Mineralogisch-Geologischen Staatsinstitut in Hamburg (Hamburg)

Summary of Operations, California Department of Natural Resources (San Francisco)

THE ASSOCIATION ROUND TABLE

EXECUTIVE COMMITTEE MEETING, TULSA, OCTOBER 4, 1929

The executive committee met at Association headquarters, 504 Tulsa Building, Tulsa, Oklahoma, October 4, 1929, with four members present, namely, president J. Y. Snyder of Shreveport, Louisiana, past-president R. S. McFarland of Tulsa, Oklahoma, second vice-president A. R. Denison of Fort Worth, Texas, and third vice-president F. H. Lahee of Dallas, Texas.

Life Member.—Charles P. McGaha was granted life membership in the Association after approval of his application according to the constitution.

New Orleans Meeting.—Plans were made for the fifteenth annual meeting, which will be held at the Roosevelt Hotel, New Orleans, Louisiana, March 20, 21, and 22, 1930.

LIFE MEMBER

CHARLES P. MCGAHA, vice-president of the Fain-McGaha Oil Corporation, Wichita Falls, Texas, having fulfilled the requirements of the Constitution, has been granted life membership in the Association by the Executive Committee.

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these applicants, please send it promptly to J. P. D. Hull, Business Manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each applicant.)

FOR ACTIVE MEMBERSHIP

Dorsey Hager, San Antonio, Tex.
F. B. Plummer, Ben C. Belt, Alex W. McCoy

NEW ORLEANS MEETING, MARCH 20-22, 1930

The following announcement has been mailed to every member of the Association.

The 15th annual meeting of the American Association of Petroleum Geologists will be held at the Roosevelt Hotel, New Orleans, Louisiana, on Thursday, Friday, and Saturday, March 20, 21, and 22, 1930.

Because this meeting will be quite different from previous gatherings, particularly as regards location and management, the executive committee is

giving it careful thought and desires especially that the members be fully informed of the new character of the meeting so that they will be ready with their whole-hearted personal coöperation.

This will be the first year that a local committee of members has not taken full responsibility for the financial, social, and scientific success of the meeting. This year we will not be dependent upon oil companies and supply houses to finance the meeting. The meeting will be held in a city where we have only one member; the nearest organization of petroleum geologists in the state is at Shreveport, more than 300 miles distant. The Association, itself, will stage this meeting,—with the assistance of the New Orleans Convention and Publicity Bureau, the Roosevelt Hotel, the Shreveport Geological Society, and Professor R. A. Steinmayer of Tulane University,—with the executive committee, however, in full charge. The third vice-president, Dr. F. H. Lahee, Box 953, Dallas, Texas, has charge of the technical program. Hotel registration is in charge of the Roosevelt Hotel. Information about hotel accommodations and rates will be sent each member. Local entertainment, sight-seeing, and the convention registration are to be provided by the New Orleans Convention and Publicity Bureau. More detailed notices will soon be mailed out. The railroads have granted the usual reduced rates of a fare and a half for the round trip.

This year we expect something unique in entertainment and local setting, at the same time maintaining the traditional scientific dignity and unity of geologic purpose which characterize this Association.

The committee announces the meeting at this early date so that you may have ample time to arrange to attend. Please respond promptly to all requests and make your plans at once to attend and help to make this the most successful A. A. P. G. meeting in the most interesting city in America.

THE EXECUTIVE COMMITTEE

MANUSCRIPTS FOR THE NEW ORLEANS MEETING, MARCH 20-22, 1930, MAY BE PREPRINTED IN PART OR IN FULL, IF THEY SEEM TO JUSTIFY IT, ONLY IF THEY ARE RECEIVED BY F. H. LAHEE, CHAIRMAN PROGRAM COMMITTEE, BOX 953, DALLAS, TEXAS, OR BY THE BUSINESS MANAGER, BOX 1852, TULSA, OKLAHOMA, ON OR BEFORE JANUARY 15, 1930.

CARBON RATIOS AND OIL GRAVITIES IN ROCKY MOUNTAIN REGION

In C. E. Dobbin's paper, "Carbon Ratios and Oil Gravities in the Rocky Mountain Region," in the October *Bulletin*, these corrections should be made: Plate 12—top numbers in columns, "Kevin-Sunburst," "Flat Coulee," and "Pondera," are carbon ratios and should have circles around them; the lowest number in column "Elk Basin" should be in the corresponding position in column "Frannie;" page 1249, line 9—30° gravity should be 38°.

Memorial

PAUL FRANKLIN MORSE

Paul Franklin Morse, geologist with The Texas Company, in charge of the San Antonio district, died at Seguin, Texas, on July 12, 1929, following a brief illness and an operation for appendicitis.

Paul was born in Wellston, Ohio, July 24, 1897. His education and training began in 1902 when his father entered Ohio State University. As a lad of ten he was taking practically all geologic trips at State University and working with his father on the Maxville limestone. In 1913 Paul entered Hyde Park High School when his father entered the University of Chicago. In 1914 he was assistant to him on the Illinois Geological Survey. In mid-school year his mother took him from North High in Columbus, Ohio, to Soldan High in St. Louis to join his father, then at Washington University. However, Paul returned to North High the following year (1915-16), where, by pursuing extra courses under Ohio State instructors, he finished high school in three and a half years.

Rejoining his parents, Paul attended Washington University two years, making many extra trips in geology. The freshman vacation (1917) he spent in oil work in Texas. He moved with his parents to Mississippi Agricultural and Mechanical College in 1918, attending it as a member of the S. A. T. C. He then entered Ohio State University as a senior, receiving the bachelor's degree in geology in 1920. In spite of all earlier geological contacts, Paul did not announce until late in his undergraduate days his intention of making geology his life work.

After graduation, Paul again joined his parents and engaged in commercial work. Within six months he was appointed assistant state geologist of Mississippi (1921-22). Later he resigned, and again became associated with his father in consulting work. During this association he prospected and surveyed the aluminum ores in Mississippi and Alabama. By request, Paul prepared a comprehensive report, "The Bauxite Deposits of Mississippi," published as Bulletin 19 of the Mississippi State Geological Survey.

On an eastern field trip of 5,000 miles in the summer of 1923 and a western trip of 10,000 miles in the summer of 1924, with geology students from Agricultural and Mechanical College, he visited almost every state in the Union.

In 1923 Paul entered the University of Chicago, using the bauxite report as a thesis for the master's degree, which was granted the first year. He was awarded a fellowship, and was elected to Sigma Xi and to Gamma Alpha at Chicago.

At the close of the winter quarter in 1924-25, Paul resigned at Chicago to accept a position as geologist with the Rycade Oil Corporation in Texas. Later he was with the Humphreys Corporation (1925-26), the Moody Corporation (1926-27), and finally The Texas Company (1927-29), all in Texas. Here

PAUL FRANKLIN MORSE
1897-1929

he spent the remainder of his professional career, a career brought so suddenly to a close after it had been wrought with such great care and enriched by such wide experience, at the very threshold of productivity, for only a few days after his passing the Darst Creek oil field was opened. "It will be a monument to Mr. Morse's work," writes his assistant.

As father and son, as teacher and student, and as pals, it is the sacred privilege of few fathers and sons to be more closely associated; and yet, close as those triple ties were, the tie between mother and son was even closer—in the finer things of life.

Paul was not only a scholar, a geologist, a devoted husband and father, but a man and friend—attested by the banks of floral offerings from his associates and friends: the most touching, perhaps, being the one completely covering the casket and bearing the message: "Your friends miss you, Old Pal." He left behind a record unsoiled by any act of dishonor.

In addition to Sigma Xi and Gamma Alpha, Paul's scholarship and research won for him election to the American Association for the Advancement of Science, the American Association of Petroleum Geologists, the Society of Economic Paleontologists and Mineralogists, and the San Antonio Geological Society. He was a member of the Knights Templar and of the Presbyterian Church.

He is survived by his wife, formerly Miss Mary Yvonne Hamilton, of Grenada, Mississippi; a daughter, Eleanor Yvonne, two years old; and his parents, Dr. and Mrs. W. C. Morse, of Agricultural and Mechanical College, Mississippi; and, in addition, by a large number of friends who admired him for his personal qualities and achievements.

SAN ANTONIO GEOLOGICAL SOCIETY
and W. C. MORSE

October, 1929

AT HOME AND ABROAD

PROPOSED CONSTITUTIONAL REVISION

President Snyder has appointed a committee to consider a revision of the A. A. P. G. constitution in the hope that it will be able to report to the Business Committee at the March, 1930, meeting. The members so far appointed are Max W. Ball, chairman, Donald C. Barton (Houston), Sidney Powers (Tulsa), George R. Stevens (Shreveport). Additional members will be appointed.

The committee desires to make its consideration thorough and to have before it the ideas of the membership. The chairman therefore asks that every member get out the constitution (*Bulletin* for June, 1929, pp. 703-6) and read it and submit any suggestions he may have. This should be done promptly, as the time between now and the March meeting is none too long. Send your suggestions to Max W. Ball, First National Bank Building, Denver, Colorado, or to the business manager.

H. B. GOODRICH, consulting geologist, Tulsa, Oklahoma, has an article on "Reports on Old Fields Important" in the *Oil and Gas Journal*, September 26, 1929.

ROY E. COLLOM is general manager of the California division of the Continental Oil Company.

GEORGE SHEPPARD, Guayaquil, Ecuador, is the author of an article on "Marine Denudation in Ecuador" in the September issue of the Pan-American Geologist.

R. B. RUTLEDGE has resigned from the Barnsdall Oil Company at Wichita to become head of the land and geological departments of the Skelly Oil Company at El Dorado, Kansas.

T. F. NEWMAN has resigned from the Midwest Exploration Company at Amarillo, Texas, to join the Skelly Oil Company there as subsurface geologist.

WILLIAM J. WRIGHT has accepted the position of provincial geologist to the Province of New Brunswick. His address is in care of Department of Lands and Mines, Fredericton, New Brunswick, Canada.

The Shawnee Geological Society held its first fall meeting, September 23, at the Hilton Phillips Hotel, Shawnee, Oklahoma. The program, arranged by IRA H. CRAM, president of the Tulsa Paleontological Society, included talks on correlation methods by H. S. THOMAS, F. A. BUSH, and G. S. BUCHANAN, all of Tulsa.

JOSEPH H. TURNER is geologist for the Independent Oil and Gas Company at San Antonio, Texas.

ROBERT B. CAMPBELL, consulting geologist, announces the removal of his offices to Suite 800-802 Western Reserve Building, San Angelo, Texas.

A. R. DENISON, division geologist for the Amerada Petroleum Corporation at Fort Worth, Texas, and second vice-president in charge of finances of the A. A. P. G., was married to Miss Maud Espy on October 8 at Timpson, Texas.

CHARLES R. FETTKE, professor of geology at the Carnegie Institute of Technology, Pittsburgh, Pennsylvania, W. A. COPELAND, assistant professor, and W. H. SEIFERT completed the field work on the geological survey of the Bradford oil field of northwestern Pennsylvania and adjacent parts of New York state during the past summer for the Pennsylvania Topographic and Geologic Survey, and have returned to Pittsburgh.

W. A. WALDSCHMIDT has been appointed assistant professor of geology at the Colorado School of Mines, Golden, Colorado. He is also retained by the Mid-West Refining Company, of Denver.

The Panhandle Geological Society entertained with a dinner and dance at the Herring Hotel, Amarillo, Texas, September 20. Following the dinner C. DON HUGHES presented a motion picture program of various National Parks and aërial views of Amarillo and vicinity. Sixty-four guests were present.

ARTHUR KNAPP was the A. A. P. G. representative at the Third National Fuels meeting at Philadelphia, Pennsylvania, last October.

BERNARD H. LASKY, Atlas Life Building, Tulsa, Oklahoma, has been in the oil fields of California a couple of months, with temporary headquarters at Los Angeles.

WILLIAM J. MILLARD and ROBERT E. KING went to Bogota some time ago to undertake a geological survey of The Texas Company's holdings in Colombia.

S. L. GILLAN, mining engineer and geologist, Los Angeles, California, attended the World Engineering Congress in Tokio, Japan, October 30 to November 20, as a delegate from the Engineers Club of Los Angeles.

EDWARD BLOESCH, consulting geologist, Tulsa, Oklahoma, had an article on "Enforcement of Existing Gas Waste Laws Would Prevent Overproduction" in *National Petroleum News*, September 25, 1929.

F. G. CLAPP, now of Paris, and F. O. MARTIN of Los Angeles, California, attended the Second Congrès International de Forages, which was held September 16-23 in Paris and other places in France.

D. R. SEMMES' address is now 429 Milam Building, San Antonio, Texas.

J. E. EATON reports receiving letters from two geologists who recall meeting him at the International Geological Congress in 1922, and on delightful trips through Belgium. Mr. Eaton states that the nearest he ever came to Belgium was the Argonne forest, that his companions there were not geologists, and that the trip was not delightful. Members are cautioned to observe initials more closely.

F. O. MARTIN of Los Angeles, California, is the author of an article on "Explorations in Colombia," in the October issue of *Geographical Review.*

WALLACE E. PRATT has been appointed by President J. Y. SNYDER to be chairman of the general business committee for the New Orleans meeting, March 20-22, 1930. It has been customary to hold the business committee meeting on the day immediately previous to the opening of the convention. Definite notice of this will be given later. Members with any business they wish to have considered by the Association should submit it to their district representatives, whose names appear in the *Bulletin* opposite the Table of Contents.

C. A. HEILAND, professor of geophysics, Colorado School of Mines, Golden, has an article on "Development in Science of Geophysics," in the October 10 issue of the *Oil and Gas Journal.*

JOSEPH JENSEN, MCDOWELL GRAVES, W. D. GOOLD, and M. L. GWIN, of the petroleum engineering department, Associated Oil Company, Los Angeles, California, published an article on "Analysis of Santa Fe Springs Field," in the *Oil and Gas Journal* of October 10.

The San Antonio Section of the A. A. P. G. listened to a talk on "Salt Domes of Southern Mexico," by PAUL WEAVER, October 7, and a talk on "Possibilities of Deeper Pennsylvanian Production in Parts of Texas, New Mexico, Colorado, and Utah," by DOUGLAS R. SEMMES, October 14.

DAVID DONOGHUE has resigned as director of the Texas Pacific Coal and Oil Company in charge of land and geological work, and is now an executive assistant to E. H. SALRIN, president of the Tidal Oil Company, Tulsa, Oklahoma. Mr. Donoghue remains in Fort Worth, Texas.

KENNETH HARTLEY CRANDALL and Miss CLAIRE CARPENTER WOFFORD were married, Thursday, October 17, at Dallas, Texas.

CHARLES A. STEWART has resigned as division geologist for the Dixie Oil Company at San Antonio to accept a position with the San Antonio office of the Shell Petroleum Corporation.

The Shreveport Geological Society elected the following officers at its first fall meeting at Shreveport, Louisiana, October 4, 1929: president, M. W. GRIMM of the Tidal Oil Company; vice-president, C. M. DORCHESTER of the Gulf Refining Company; and secretary-treasurer, W. F. CHISHOLM of the Louisiana State Conservation Department.

MARVIN LEE, of Wichita, Kansas, has been re-elected representative of the Wichita district of the A. A. P. G. for the term 1930-1931.

The Fort Worth Geological Society has the following officers: president R. A. LIDDLE of The Pure Oil Company; vice-president, A. R. DENISON of the Amerada Petroleum Corporation; and secretary-treasurer, C. E. YAGER of the Texas Pacific Coal and Oil Company.

The Houston Geological Society has elected new officers as follows: president, GEORGE SAWTELLE of the Kirby Petroleum Company; vice-president, J. BRIAN EBY of the Shell Petroleum Corporation; and secretary-treasurer, JOHN F. WEINZIERL, 607-8 Petroleum Building.

MAX W. BALL talked on the subject "Rocky Mountain and Western Great Plains Prospects," before the Tulsa Geological Society, October 21, 1929.

GEOPHYSICAL NOTES

The Imperial Geophysical Experimental Survey, under the direction of A. Broughton Edge, has been making an extensive field investigation of geophysical methods in Australia. Gravimetric surveys have been made of the Victoria brown coal field and of the Lakes Entrance oil district. Electrical surveys have been made in several mining districts. Seismic prospecting is being carried out in the Gulgong gold district. (*Mining Magazine*, London, August, 1929).

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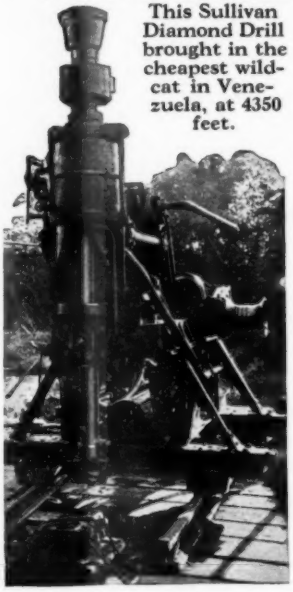

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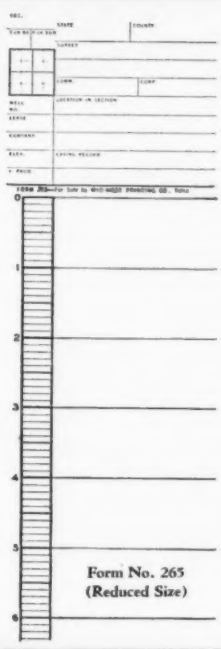

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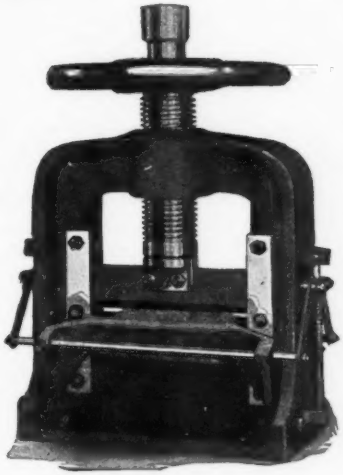

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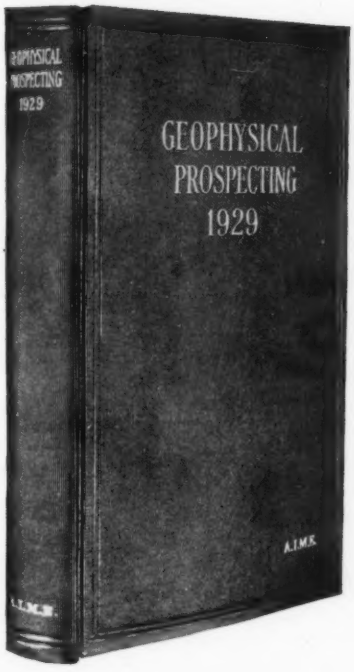

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